UNIVERSIDADE FEDERAL DO PARANÁ

FELIPPE ALEXANDRE LISBOA DE MIRANDA DAROS

ESTUDO DA ICTIOFAUNA COSTEIRA NO LITORAL DO PARANÁ E ADJACÊNCIAS ATRAVÉS DE CENSOS VISUAIS E MICROQUÍMICA DE OTÓLITOS

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Tese apresentada ao curso de Pós-Graduação em Ciências Biológicas – Zoologia, Setor de Ciências Biológicas da Universidade Federal do Paraná, como requisito parcial à obtenção do título de Doutor em Ciências Biológicas área de concentração Zoologia.

Orientador: Prof. Dr. Henry L. Spach

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"ESTUDO DA ICTIOFAUNA COSTEIRA NO LITORAL DO PARANÁ E ADJACÊNCIAS ATRAVÉS DE CENSOS VISUAIS E MICROQUÍMICA DE OTÓLITOS"

Tese aprovada como requisito parcial para obtenção do grau de Doutor em Zoologia, do Setor de Ciências Biológicas da Universidade Federal do Paraná, pela seguinte Comissão Examinadora:

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Índice

Resumo

Os habitats costeiros estão entre os ambientes mais produtivos e utilizados do planeta, formados por diferentes ecossistemas, abrigando uma grande diversidade de espécies. Historicamente, esses ecossistemas sofrem diretamente com as ações antrópicas, causando assim a perda de habitat, e inviabilizando o seu uso pelos organismos. Nos estuários e zonas costeiras, os peixes são conhecidos por possuírem alta riqueza de espécies de grande importância ecológica e econômica, contudo, são fortemente pressionados pelas ações antropogênicas. Os objetivos deste trabalho foram: (i) gerar uma lista de espécies de peixes observadas nas ilhas de Currais e Itacolomis; (ii) caracterizar a estrutura da comunidade de peixes de costão rochoso através de censo visual subaquático nas Ilhas de Currais, Itacolomis e no Arquipélago das Graças; (iii) caracterizar as assinaturas químicas dos otólitos entre as ilhas costeiras do litoral do Paraná e adjacentes através da análise química de otólitos da donzelinha, *Stegastes fuscus*; (iv) e estudar o uso do habitat de juvenis de robalo-peva, *Centropomus parallelus* em dois locais no Complexo Estuarino de Paranaguá (Guaraguaçu e Tromomó) através da análise química e microestrutura de otólito. Nossos resultados mostram que a composição taxonômica é semelhante entre as ilhas, mas que existem diferenças tanto em densidade quanto em biomassa, evidenciando que a estruturação das assembleias ocorre de forma diferenciada, seja por fatores ambientais e/ou antrópicos, e dominadas tanto em densidade quanto em biomassa por poucas espécies. A assinatura química dos otólitos entre as ilhas de *S. fuscus*, mostrou uma diferenciação entre as populações das ilhas baseada na distância dos estuários, onde houve uma diferenciação na composição elementar da ilha da Galheta com as demais devido sua proximidade com o Complexo Estuarino de Paranaguá. A Ilha de Bom Abrigo e Arquipélago das Graças, distantes a poucas milhas náuticas da desembocadura das Baía de Cananéia e Babitonga (respectivamente) são mais semelhantes entre si do que as ilhas mais afastadas (Arq. Currais, Figueira e Itacolomis). A análise da relação Sr:Ca, do núcleo até a borda dos otólitos dos juvenis de *C. parallelus* mostraram que os indivíduos podem ocorrer em habitats de diferentes salinidades e migrar entre água doce até marinha, mostrando uma grande plasticidade ambiental.

Palavras-chave: Lista de espécies, distinção taxonômica, conectividade, microquímica de otólito, plasticidade

Abstract

The coastal habitats are among the most productive and used environment in the world, formed by different ecosystems, with a great species diversity. Historically, these ecosystems suffer directly from anthropogenic actions, causing the loss of habitat, compromising the biota's usel. In estuaries and coastal areas, fish are known to have high species richness of great ecological and economic importance. However, they are heavily impacted by human activities.. The objectives of this study were: (i) generate a list of fish species observed on the islands of Currais and Itacolomis; (ii) characterize the structure of the fish community of rocky shore through underwater visual census of the Islands Currais, Itacolomis and the Archipelago of Graças; (iii) characterize the otoliths fingerprint between the coastal and adjacent coast of Paraná, through chemical analysis of otoliths of damselfly, *Stegastes fuscus*; (iv) and study the habitat use of juvenile fat snook, *Centropomus parallelus* in two locations in the Paranaguá Estuarine Complex (Guaraguaçu and Tromomó) through chemical analysis and microstructure of the otolith. Our results show that the taxonomic composition is similar between the islands, but there are differences in both density and biomass, indicating that the structure of the assemblies occurs differently, either by environmental and/or human factors, and dominated both in density and biomass by a few species. The *S. fuscus* otoliths fingerprint showed a differentiation between populations of the islands based on the distance of estuaries.There was a difference in the elemental composition of the island of Galheta with others islands due to its proximity to the Paranaguá Estuarine Complex. The Bom Abrigo Island and Graças Archipelago, distant a few nautical miles from the Cananeia and Babitonga Bay (respectively) are more similar than more distant islands (Archipelago of Currais, Figueira and Itacolomis islands). The analysis of the Sr:Ca ratios, core to the edge of the otoliths of juveniles of *C. parallelus* showed that individuals may occur in habitats with different salinities and migrate from freshwater to marine, showing a high environmental plasticity.

Keywords: checklist, taxonomic distinctiveness, connectivity, otoliths microchemistry, plasticity

Introdução geral

Globalmente a zona costeira é um dos ambientes naturais mais utilizados pelo homem (Halpern et al. 2008), composto por diversos compartimentos interligados (manguezal, bancos de gramas marinhas, substratos consolidados e inconsolidados), abrigando uma grande diversidade de espécies (Ogden et al. 2005), criando assim condições para a dispersão de diversas espécies entre diferentes habitats (Unsworth et al. 2008). Historicamente, esses ecossistemas sofrem diretamente com as ações antrópicas (ex. especulação imobiliária, construção de portos, esgoto industrial e urbano, entre outros) causando assim a perda de habitat, e inviabilizando o seu uso pelos organismos (Barbier et al. 2011). Portanto, quaisquer alterações nestes frágeis ecossistemas, podem interferir diretamente no ciclo de vida de grande parte das espécies marinhas, e atingir direta e decisivamente o equilíbrio da cadeia alimentar, alterando toda a estrutura do ecossistema.

Entre os ecossistemas que compõem a zona costeira, os estuários e os recifes, são juntos, responsáveis, pela maior parte da produção de biomassa nos oceanos, geralmente conectados pelos processos de dispersão e/ou migração dos organismos. Os estuários são conhecidos como as principais áreas de berçário, abrigando juvenis de diversas espécies de peixes (Mumby et al. 2004), que utilizam suas águas, em algum momento do ciclo de vida, como área de recrutamento, alimentação e ou reprodução (Potter et al. 1986), pois possuem uma alta produtividade e habitats propícios para proteção contra predadores (Laegdsgaard e Johnson, 2000).

Os recifes formados por fundo consolidado, de origem orgânica e/ou inorgânica, incluindo ainda, áreas de fundo de areia, cascalho ou mista, adjacente ao recife (Carvalho-Filho et al. 2005), são extremamente ricos e complexos no ecossistema marinho no qual as comunidades de peixes atingem o seu maior nível de diversidade (Sale, 1991), embora esta diversidade varie conforme as condições geográficas e morfológicas. Esses recifes abrigam mais de 25% de todas as espécies de peixes marinhos já descritas (Spalding et al. 2001).

No Brasil, aproximadamente 559 espécies ocupam estes ambientes (Carvalho- Filho e Floeter, dados não publicados), apresentando uma ampla variedade de cores, formas, hábitos tróficos, reprodutivos e inúmeras associações intra e interespecíficas (ver Hostim-Silva et al. 2006). Com essa riqueza e diversidade, os peixes recifais constituem complexas comunidades nos costões rochosos. Apesar de

apresentar uma menor complexidade topográfica quando comparados a recifes de corais, os costões podem abrigar uma variada fauna e flora associada (Rocha e Faria, 2005; Horta et al. 2007; Lorenzi e Borzone, 2009). No sudeste e sul do Brasil, os costões rochosos representam o principal habitat para a biota recifal (Ferreira et al. 2001). O conhecimento da ecologia de peixes de costões rochosos naturais obteve maior interesse científico nas últimas duas décadas, em especial quanto ao estudo dos aspectos que determinam a estrutura da ictiofauna. Nos costões naturais, a abundância e diversidade dos peixes são afetadas pela zonação da região entre marés e do infralitoral (Alevizon *et al*., 1985) pois, em cada uma das zonas, a composição do substrato e o crescimento da fauna e flora bêntica, de forma diferenciada, resultam em uma disponibilidade distinta de abrigo e alimento.

A associação do habitat e dos peixes pode envolver vários fatores bióticos e abióticos que atuam em diferentes escalas espaciais e temporais, influenciando fortemente na escolha dos habitats e na abundância e distribuição de muitos peixes recifais (Costello, 1992; Sale *et al*., 1994; Syms, 1995; Reñones *et al*., 1997; García-Charton & Pérez-Ruzafa, 1998; Macpherson & Zika, 1999).

Dentre várias ferramentas utilizadas para acessar estas informações, o censo visual subaquático vem sendo utilizado intensivamente em estudos de dinâmica de populações, ecologia e manejo de peixes recifais desde a década de 1950 (Brock 1954; Ferreira et al. 2001; Godoy et al. 2007; Floeter et al. 2007). Esta permite uma rápida estimativa da riqueza, abundância relativa e frequência de comprimento dos peixes associadas ao substrato consolidado. Por esta razão, tem sido utilizada para a contagem de uma vasta gama de espécies demersais que são utilizadas como recursos pesqueiros (Samoilys, 1988; Machado et al. 2003; Sampaio, 2003). Esta metodologia não destrutiva é a ideal para trabalhos realizados em áreas de substrato complexo, como as áreas recifais, onde os dados a serem coletados não necessitam a retirada dos animais de seu ambiente. O método ideal de censo visual subaquático irá variar com a situação, dependendo dos objetivos do estudo e das dificuldades logísticas, e nas características das espécies-alvo (densidade, isolamento, tamanho do animal, mobilidade, respostas comportamentais aos mergulhadores), nível de formação dos censores, clareza da água, profundidade, tipo de habitat, onda e exposição do costão (Edgar et al. 2004).

Além de serem utilizados para estimar a idade e crescimento dos peixes ósseos (ex. Francis & Campana, 2004; Mendoza, 2006; Correia *et al*., 2009), os otólitos

(formados por concêntricas camadas de $CaCO_3$) também são utilizados como marcadores naturais nos estudos de migração (ex. Correia *et al*., 2004; Gillanders, 2005; Albuquerque *et al*., 2012), diferenciação de estoques pesqueiros (ex. *C*orreia *et al.,* 2011*;* Geffen *et al*., 2011; Silva *et al.,* 2011)*,* determinação de locais de nascimento (ex. Di Franco *et al.,* 2011; Hamer *et al.,* 2011) e estudo da conectividade entre berçários e zonas de recrutamento costeiro (ex. Reis-Santos *et al*., 2012). Isto é possível, pois além de $CaCO_3$ e otolina (matriz proteica), outros elementos são depositados em pequenas concentrações, e estes não sofrem transformações ou modificações químicas à posteriori (Campana e Neilson, 1985), portanto funcionam como marcadores (Campana *et al*., 2000), apresentando uma relação previsível entre os elementos no ambiente e sua concentração nos otólitos (Elsdon et al. 2008).

Objetivos

- i. Gerar uma lista de espécies da fauna ictiológica do costão rochoso do Arquipélago de Currais e da Ilha de Itacolomis com detalhes sobre a distribuição geográfica, guildas funcionais e relações intra-específicas (Capítulo I).

- ii. Conhecer a estrutura da assembleia de peixes de costão rochoso do Arquipélago de Currais, Ilha de Itacolomis e das ilhas do Arquipélago das Graças (SC), com detalhes sobre a distribuição geográfica, guildas tróficas e comparações da densidade, biomassa por unidade de área, além da utilização dos índices de Distinção Taxonômica Média e Variação na Distinção Taxonômica (Capítulo II).

- iii. Caracterizar a assinatura química elementar dos otólitos da donzelinha, *Stegastes fuscus*, entre as ilhas costeiras do litoral do Paraná (Figueira, Galheta, Currais e Itacolomis), Bom Abrigo (SP) e Arquipélago das Graças (SC), espécie está que apresentou a maior frequência de ocorrência e abundância nas ilhas estudas no objetivo ii (Capítulo III).

  iv. Avaliar o uso do habitat por juvenis de *Centropomus parallelus* coletados em dois locais do Complexo Estuarino de Paranaguá (robalo-peva), através da análise microquímica (Sr:Ca) e de microestrutura (incrementos diários) dos otólitos (Capítulo IV).

Capítulo I

Check List 8(3: 349-354, 2012

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Check List
Journal of species lists and distribution

Lists of Species

Checklist of rocky reef fishes from the Currais Archipelago and Itacolomis Island, Paraná state, Brazil

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Abstract: The ichthyofauna of the rocky substrate of Currais Archipelago and Itacolomis Island (Paraná state, Brazil) was surveyed between October 2008 and August 2009 through visual census, using 40 m^2 (20x2 m) band transects at an average depth of 6 m. A total of 14,210 individuals (66 species from 33 families) were observed in 336 band transects, covering an area of 13,440 m^2. *Stegastes fuscus*, *Abudefduf saxatilis*, *Haemulon aurolineatum* and *Malacoctenus delalandii* were the most abundant species. "Carnivore" was the most species-rich category, and "Mobile Invertebrate Feeder" the most abundant. Nine species are added to the list of reef fishes of the Paraná state: *Acanthurus coeruleus*, *Dactylopterus volitans*, *Epinephelus morio*, *Myrichthys breviceps*, *Ophioblennius trinitatis*, *Paraclinus spectator*, *Scorpaena brasiliensis*, and *Selene vomer*.

Introduction

Reefs are defined as any formation with a consolidated bottom of organic and/or inorganic origin and they are extremely rich in terms of biodiversity and form one of the most complex environments in the coastal marine ecosystem. It is estimated that reefs harbor about 25% of all species of marine fishes currently known (Spalding *et al.* 2001). Fish communities have the highest levels of diversity in reefs, though such diversity may vary according to geographic and morphologic conditions of the ecosystem (Sale 1991). In Brazil, it is estimated that about 520 species inhabit this ecosystem (Hostim-Silva *et al.* 2006). Those species display a plethora of colors, shapes, trophic and reproductive habits, and present a variety of intra- and interspecific associations.

Rocky shore support diverse fish communities despite having lower topographic complexity than coral reefs, and are the main habitat for the reef biota in southern Brazil (Ferreira *et al.* 2001). Consolidated substrates such as those typically present in coastal islands, rocky shores, submerged slabs and calcareous bottoms are uncommon in the coast of Paraná State, southern Brazil. It is possible that the almost complete inexistence of such rock formations in the coast line of Paraná might be related to the relatively large distance of the Serra do Mar, where the rocky formations are found. The Currais Archipelago and Itacolomis Island are ecologically relevant among the marine ecosystems of the Paraná State since they supply suitable conditions for communities whose components are more adapted to living in reef habitats.

Despite its relevance to the marine biota, few studies have been performed to date in these islands (Félix and Harckradt 2008; Félix-Hackradt and Hackradt 2008; Harckradt and Félix-Harckradt 2009). Many studies that deal with the fish fauna have been carried out on the Paraná coast, but the main focus of those studies was usually the ichthyofauna associated with unconsolidated substrate (*e.g.* Godefroid *et al.* 2001; Vendel *et al.* 2003; Spach *et al.* 2004; Félix *et al.* 2007). In order to contribute to the knowledge of this particular component of the ichthyofauna, a list of the fish species known to occur in the rocky substrates of the Currais Archipelago and Itacolomis Island is provided.

Materials and Methods

Study site

The Currais Archipelago (25°44' S, 48°22' W) is composed of three islands separated by 6 nautical miles from the coast. The depth along the archipelago varies from 1.5 to 16 m. Itacolomis Island (25°50' S, 48°24' W) consists of two small rocky islands located approximately 7 nautical miles from the coast, with depths ranging from 3 to 17 m (Figure 1). The inclination of the rocky shores of Currais Archipelago and Itacolomis Islands is moderate, between 45° and 60°. The substrate is composed mostly of small rocks, which are usually covered by macroalgae, *Palythoa* sp., and *Zoanthus* sp.

Data collection

Data were collected using underwater visual census (UVC) on strip transects (Floeter *et al.* 2007). Observations were conducted monthly, from October 2008 to August 2009, from 07:00 a.m. to 03:00 p.m. A total of 336 strip transects of 40 m^2 (20x2 m) each were analyzed, 168 on each site: two in Currais Archipelago and two in Itacolomis Island (Figure 1), using SCUBA gear in depths that ranged from 3 to 9 m. The total area covered in the study was 13,440 m^2.

Species were identified with the use of keys and descriptions provided by Figueiredo and Menezes (1980), Menezes and Figueiredo (1980, 1985), Randall (1996), Humann and Deloach (2002), Hostim-Silva *et al.* (2006), Craig and Hastings (2007), and Baldwin *et al.* (2009). For the genus *Kyphosus*, the differentiation between the two

species, *K. incisor* and *K. sectator*, is possible only with the capture of specimens for counting spines of the dorsal and anal fins; thus the specimens observed were identified until the taxonomic level of genus. The species of reef fishes were grouped in six trophic categories assessed from the literature (Ferreira *et al*. 2004; Randall 1967; Opitz 1996; Floeter *et al*. 2004, 2006; Kuiter 2009), where: CAR = Carnivores (eat a variety of mobile organisms, including invertebrates and fishes), MIF = Mobile Invertebrate Feeders (feed primarily on small benthic mobile invertebrates like mollusks, crustaceans, worms, etc. associated to the hard- or nearby soft-substrate), OMN = Omnivores (feed on a variety of organisms, both animal and vegetal), PLA = Planktivores (feed primarily on macro- and micro-zooplankton), HER = Herbivores (small to large herbivores that include in their diet a rich mass of detritus, turf algae and macroalgae) and SIF = Sessile Invertebrate Feeders (feeds on a array of sessile benthic invertebrates like cnidarians, bryozoans, ascidians and sponges that are mostly associated with hard substrate).

In order to analyze their zoogeographic affinities, the species were classified using the literature (Luiz-Jr *et al*, 2008) into the following geographic distribution categories: Br = Brazilian province; CE = Central Atlantic (St. Helena and Ascension Islands); CT = Circumtropical, EA= Eastern Atlantic, Pat = Patagonian (occur primarily in the temperate rocky reefs south to Argentina), SCa = Southern Caribbean (coast of Venezuela, Trinidad and Tobago and other islands of the low Lesser Antilles), SE = Southeastern Brazil (endemic from the region that encompass 20° to 27°S), TA = Trans-Atlantic (both sides of the Atlantic Ocean), and WA = Western Atlantic (in the western North and South Atlantic).

Results and Discussion

Throughout this study, 14,210 individuals of 66 species in 33 families and 8 orders, were observed (Table 1). In the Currais Archipelago, 6,115 specimens (48 species in 30 families) were observed, with an average density of 36.4/40 m^2. On Itacolomis Island, 8,095 specimens were observed (51 species in 26 families), with an average density of 48.2/40 m^2.

The families Blenniidae, Carangidae, Epinephelidae, Haemulidae, and Pomacentridae were those with the largest number of species observed (five each). *Stegastes fuscus*, *Malacoctenus delalandii*, *Parablennius marmoreus*, and *Abudefduf saxatilis* were the most frequent species observed during the study (98.8, 86.0, 56.5 and 48.2%, respectively), while *S. fuscus* (n=3,929), *A. saxatilis* (n=2,694), *Haemulon aurolineatum* (n=2,529), *M. delalandii* (n=1,676) were the most numerous (Figure 2).

Most of the individuals observed belong to species whose maximum known TL are around 10 centimeters. Another factor that possibly contributed to this result is the ontogenetic migration of some species, such as *Mycteroperca marginata* (Machado *et al*. 2003). In that species and possibly in others among those identified in this study, smaller individuals are found in shallower depths, whereas the larger ones look for refuges at deeper sites, thus decreasing the competition for space and food.

The 66 species identified in this study were grouped in the six trophic categories described above, which can be used as categories of convenience in studies about interactions between species. About 32% (21 species) are Carnivores. Mobile Invertebrate Feeders is the second largest category, with 26% (17) of the species identified. The other categories are Herbivores, Omnivores, Planktivores, and Sessile Invertebrate Feeders (12, 9, 5, and 2 species, respectively), together contributed with 42% of the species identified. Carnivores are more representative at high latitudes, due to a decrease in herbivores and mobile invertebrate feeders (Ferreira *et al*., 2004). The diversity of the mobile invertebrate feeders, and the consequently diversified ecomorphological types, make such group prone to be abundant in different environmental conditions (Ferreira *et al*. 2004).

Fifty-nine percent of the species (39) occur throughout the Western Atlantic, 22.7% (15) are Trans-Atlantic, and 10.6% (7) are endemic to the Brazilian coast. Species that occur in the Central-Atlantic and Southeastern Brazil contribute with 6.0% (4) and 1.5% (1), respectively.

Ophioblennius trinitatis, *Selene vomer*, *Dactylopterus volitans*, *Paraclinus spectator*, *Myrichtys breviceps*, *Scorpaena brasiliensis*, *Epinephelus morio* (Figure 3A) and *Acanthurus coeruleus* (Figure 3B) are species known to occur in southern Brazil (Hostim-Silva *et al*., 2006; A. A. Bertoncini, unpubl. data), but during this study they were observed for the first time in association with rocky substrates in the Paraná State and should be added to the regional list provided by Hackradt and Félix-Harckradt (2009).

A juvenile of *Anisotremus virginicus*, which is an optional cleaner during this phase, was observed cleaning an adult of *Chaetodon striatus* for 3 minutes (Figure 4). This interaction represents a cleaning symbiosis in which one species of fish removes parasites and necrotic tissue or mucus from a variety of fish seeking services.

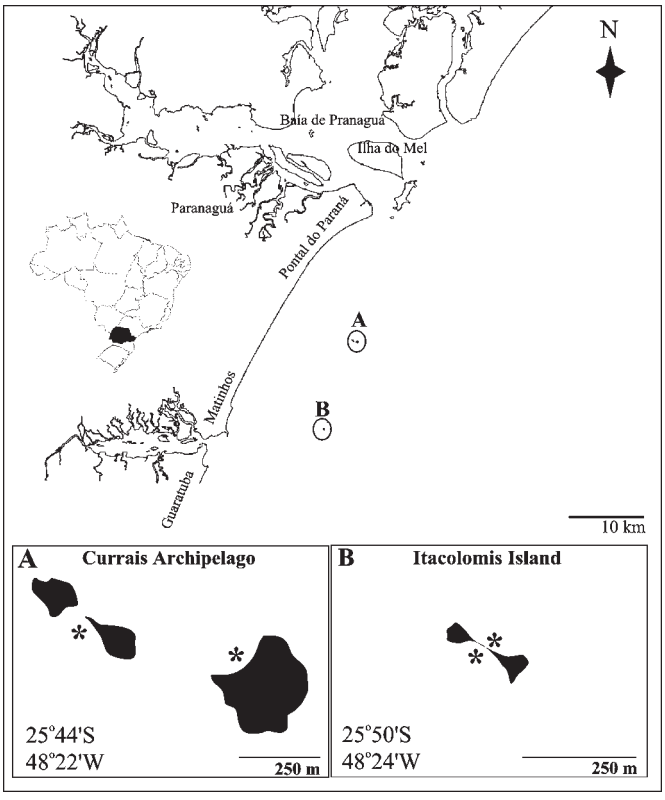

Figure 1. Paraná coast. (A) Currais Archipelago and (B) Itacolomis Island.

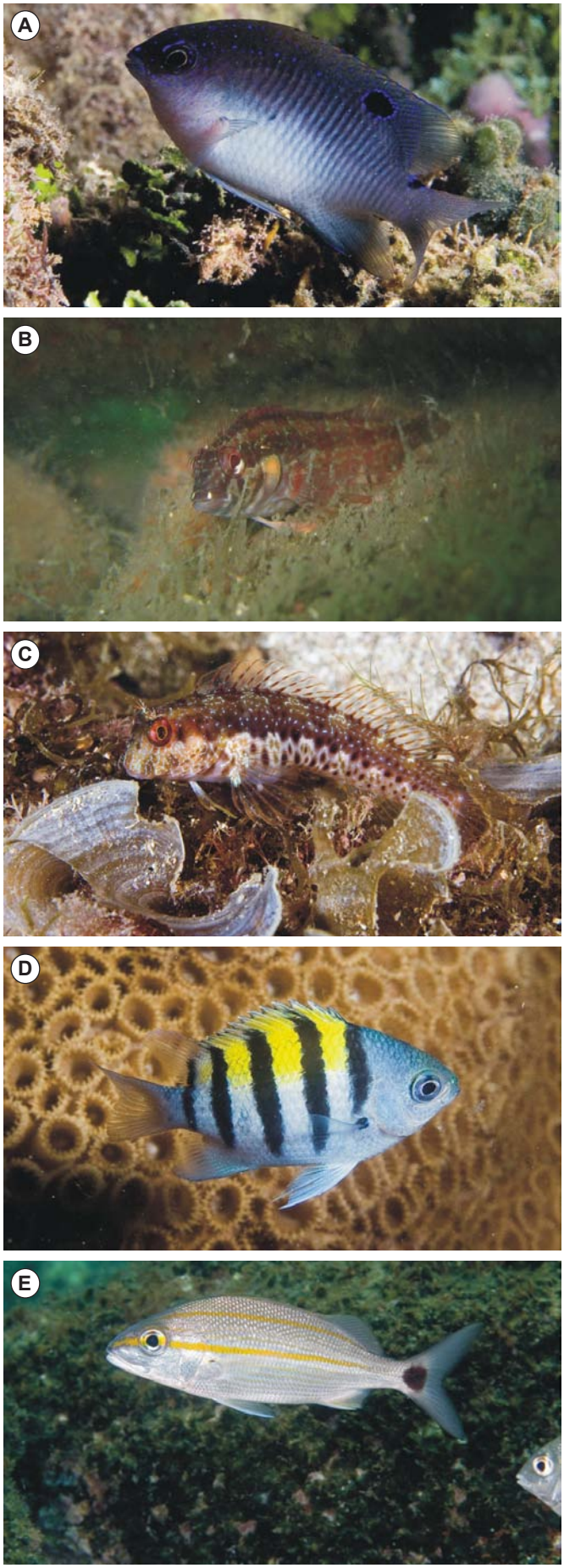

Figure 2. Species more frequent and abundant observed in the study: (A) *Stegastes fuscus*; (B) *Malacoctenus delalandii*; (C) *Parablennius marmoreus*; (D) *Abudefduf saxatilis*; and (E) *Haemulon aurolineatum*. Photos A, C, D, and E by Athila Bertoncini. Photo B by Felippe Daros.

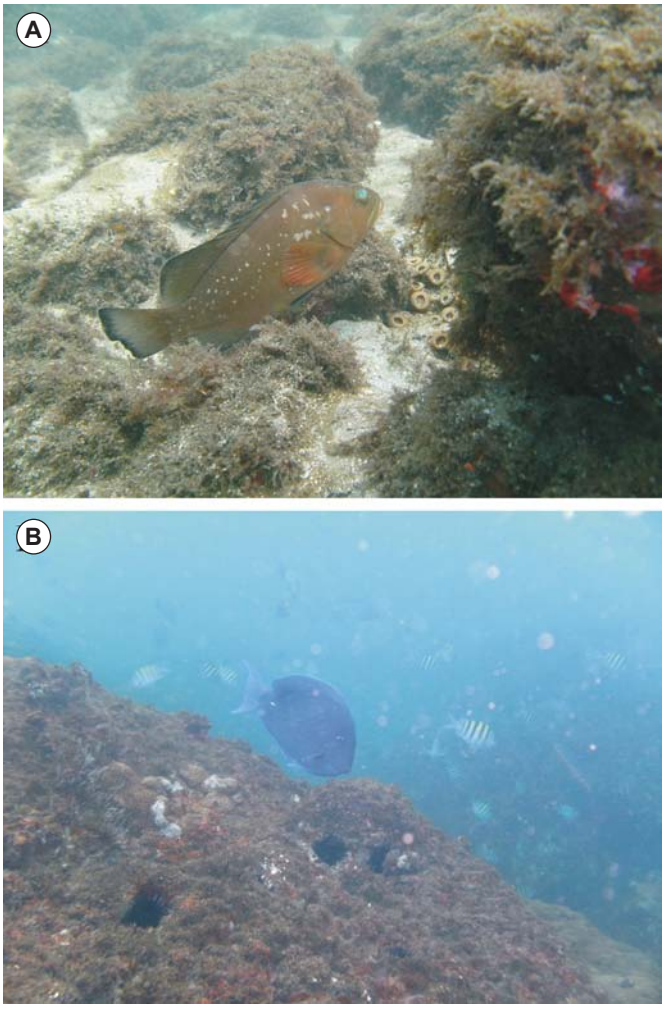

Figure 3. *Epinephelus morio* (A) in the Currais Archipelago and *Acanthurus coeruleus* (B) in the Itacolomis Island. Photos by Felippe Daros.

Figure 4. Cleaning station observed in the Currais Archipelago. *Anisotremus virginicus* and *Chaetodon striatus*. Photo by Felippe Daros.

Table 1. Abundance of species of fishes in the Currais Archipelago and Itacolomis Island. Classification follows Nelson (2006). Trophic categories: CAR, carnivore; HER, herbivore; ONI, omnivore; MIF, mobile invertebrate feeder; SIF, sessile invertebrate feeder; PLA, planktivore. Geographic range: Br, Brazilian province; CE, Central Atlantic; CT, Circumtropical; EA, Eastern Atlantic; Pat, Patagonian; SCa, Southern Caribbean; SE, Southeastern Brazil; TA, Trans-Atlantic; WA, Western Atlantic.

LIST OF SPECIES	CURRAIS (N)	ITACOLOMIS (N)	TROPHIC CATEGORIES	GEOGRAPHIC RANGE
CHONDRICHTHYES				
Myliobatiformes				
Myliobatidae				
Aetobatus narinari (Euphrasen, 1790)		1	CAR	CT
ACTINOPTERYGII				
Anguilliformes				
Muraenidae				
Gymnothorax funebris Ranzani, 1839	1	2	CAR	WA
Gymnothorax moringa (Cuvier, 1829)	5	2	CAR	WA+CE
Gymnothorax vicinus (Castelnau, 1855)	1	4	CAR	TA
Ophichthidae				
Myrichthys breviceps (Richardson, 1848)	1		MIF	WA
Synodontidae				
Synodus synodus (Linnaeus, 1758)		*	CAR	TA
Beryciformes				
Holocentridae				
Holocentrus adscensionis (Osbeck, 1765)	26	75	MIF	TA
Gasterosteiformes				
Sygnathidae				
Micrognathus crinitus (Jenyns, 1842)	1		MIF	WA
Fistulariidae				
Fistularia tabacaria Linnaeus, 1758	1		CAR	TA
Scorpaeniformes				
Dactylopteridae				
Dactylopterus volitans (Linnaeus, 1758)	*		MIF	TA
Scorpaenidae				
Scorpaena brasiliensis Cuvier, 1829		2	CAR	WA
Perciformes				
Serranidae				
Diplectrum radiale (Quoy and Gaimand, 1824)	1		CAR	WA
Serranus flaviventris (Cuvier, 1829)	110	56	MIF	WA
Epinephelidae				
Epinephelus morio (Valenciennes, 1828)	*		CAR	WA
Hyporthodus niveatus (Valenciennes, 1828)	1	4	CAR	WA
Mycteroperca acutirostris (Valenciennes, 1828)	37	14	CAR	WA
Mycteroperca bonaci (Poey, 1860)	1		CAR	WA
Mycteroperca marginata (Lowe, 1834)	7	16	CAR	SE+Pat+EA
Priacanthidae				
Priacanthus arenatus Cuvier, 1829	*		CAR	TA
Carangidae				
Carangoides crysos (Mitchill, 1815)	1	6	CAR	TA
Caranx latus Agassiz, 1831		1	CAR	TA
Chloroscombrus chrysurus (Linnaeus, 1766)	8	20	PLA	TA
Pseudocaranx dentex (Bloch and Schemeider,1801)	115	49	PLA	CT
Selene vomer (Linnaeus, 1758)		1	CAR	WA
Lutjanidae				
Lutjanus analis (Cuvier, 1828)	2		CAR	WA
Haemulidae				
Anisotremus surinamensis (Bloch, 1791)	27	31	MIF	WA
Anisotremus virginicus (Linnaeus, 1758)	135	103	MIF	WA
Haemulon aurolineatum Cuvier, 1830	1745	784	PLA	WA
Haemulon stendachneri (Jordan and Gilbert, 1882)	5	1	MIF	WA
Orthopristis ruber (Cuvier, 1830)	22	4	MIF	WA
Sparidae				
Archosargus probatocephalus (Walbaum, 1792)		1	OMNI	WA

Table 1. ***Continued.***

LIST OF SPECIES	CURRAIS (N)	ITACOLOMIS (N)	TROPHIC CATEGORIES	GEOGRAPHIC RANGE
Diplodus argenteus (Valenciannes, 1830)	23	45	MIF	WA
Sciaenidae				
Odontoscion dentex (Cuvier, 1830)	381	361	CAR	WA
Pareques acuminatus (Bloch and Schemeider, 1801)	52	77	MIF	WA
Mullidae				
Pseudupeneus maculatus (Bloch, 1793)	46	19	MIF	WA
Pempheridae				
Pempheris schomburgkii Muller andTroschel, 1848	6	11	PLA	WA
Kyphosidae				
Kyphosus sp.	10	130	HER	TA
Chaetodontidae				
Chaetodon striatus Linnaeus, 1758	95	26	SIF	WA
Pomacanthidae				
Pomacanthus paru (Bloch, 1787)	4	2	OMNI	WA
Pomacentridae				
Abudefduf saxatilis (Linnaeus, 1758)	797	1897	OMNI	CT
Chromis multilineata (Guichenot, 1853)		2	PLA	TA
Stegastes fuscus (Cuvier, 1830)	1521	2408	HER	BR
Stegastes pictus (Castelnau, 1855)	*		HER	BR+SCa
Stegastes variabilis (Castelnau, 1855)	4	4	HER	WA
Labridae				
Bodianus rufus (Linnaeus, 1758)		4	MIF	WA
Halichoeres poeyi (Steindachner, 1867)	6	2	MIF	WA
Scaridae				
Sparisoma amplum (Ranzani, 1841)		1	HER	BR
Sparisoma axillare (Steindachner, 1878)	11	9	HER	BR
Sparisoma frondosum (Agassiz, 1831)	5	4	HER	BR+SCa
Sparisoma radians (Valenciennes, 1840)		1	HER	WA
Blenniidae				
Hypsoblennius invemar Smith-Vaniz and Acero-P., 1980		3	OMNI	WA
Ophioblennius trinitatis Miranda Ribeiro, 1919		1	HER	BR
Parablennius marmoreus (Poey, 1876)	121	306	OMNI	WA
Parablennius pilicornis (Cuvier, 1829)	8	35	OMNI	TA
Scartella cristata (Linnaeus, 1758)	4	5	OMNI	CT
Labrisomidae				
Labrisomus nuchipinnis (Quoy and Gaimand, 1824)	2	20	CAR	TA
Malacoctenus delalandii (Valenciennes, 1836)	354	1322	MIF	WA
Paraclinus spectator Guimarães and Bacellar, 2002	3		MIF	BR
Gobiidae				
Coryphopterus glaucofraenum Gill, 1863	348	26	PLA	WA
Ephippidae				
Chaetodipterus faber (Broussonet, 1782)	5		OMNI	WA
Acanthuridae				
Acanthurus bahianus Castelnau, 1855	10		HER	WA
Acanthurus chirurgus (Bloch, 1787)	5	184	HER	TA
Acanthurus coeruleus Bloch and Schneider, 1801		*	HER	WA
Scombridae				
Scomberomorus brasiliensis Collette, Russo and Zavala-Camin, 1978	4	2	CAR	WA
Tetraodontiformes				
Monacanthidae				
Stephanolepis hispidus (Linnaeus, 1766)	1	1	OMNI	TA
Tetraodontidae				
Sphoeroides spengleri (Bloch, 1785)	36	10	SIF	WA

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Capítulo II

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Estrutura da assembleia de peixes de costão rochoso de ilhas costeiras no sul do Brasil.

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Resumo

A estrutura das assembleias de peixes de costão rochoso de sete ilhas costeiras no sul do Brasil foi caracterizada através de censo visual subaquático, utilizando transecção em faixa de 20 m x 2m (40m^2) a uma profundidade média de seis metros, onde foram obtidos dados de densidade (indivíduos/40m^2) e biomassa estimada (gramas/40m^2). As espécies de peixes foram caracterizadas segundo suas categorias tróficas e distribuição geográfica. No total foram realizadas 526 transecções em faixa, cobrindo uma área de 21.040 m^2, observando 19.377 indivíduos (médias de 36,83 ind./40m^2 e 1790,23 g/40m^2) totalizando 73 espécies pertencentes a 34 famílias. Destas, 60% são espécies que ocorrem no Atlântico Ocidental, 20% são Transatlânticas e 9,60% ocorrem somente na Província Brasileira. A espécie *Stegastes fuscus* foi a mais frequente e a com maior densidade. *Acanthurus chirurgus* apresentou a maior biomassa, seguida de *S. fuscus*. A Ilha de Itacolomis apresentou a maior densidade, 48,18 ind./40m^2, seguida pela Ilha do Veado com 43,00 ind/40m^2. Com relação a biomassa a Ilha de Itacolomis e a Pedra da Baleia foram as mais representativas com valores médios de 3.253 e 3.028 g/40m^2, respectivamente. Predadores de invertebrados móveis foi a categoria trófica com a maior riqueza, representada por 26% do total de espécies observadas, possuindo ainda a maior densidade (12,57 ind./40m^2). Já Herbívoro móvel apresentou a maior biomassa (780,48 g/40m^2).

Nossos resultados mostram que, apesar da composição taxonômica ser semelhante entre as ilhas, existem diferenças tanto em densidade quanto em biomassa, evidenciando que a estruturação das assembleias ocorrem de forma diferenciada, seja por fatores ambientais e/ou antrópicos, e dominadas tanto em densidade quanto em biomassa por poucas espécies.

Introdução

O termo recifal, utilizado pela comunidade científica para designar ambientes com predominância de substrato consolidado, é normalmente associado pelo público em geral às barreiras de recifes de corais. Entretanto, devemos considerar que não são os únicos que caracterizam um ambiente recifal. Isto porque, o substrato consolidado que compõe um ambiente recifal, pode ter origem não apenas a partir dos organismos polipóides coloniais conhecidos como corais, mas também, a partir, de algas calcárias, rochas, estruturas artificiais ou mesmo associações destes (Hostim-Silva *et al.*, 2006), incluindo ainda nesta definição, áreas de fundo de areia, cascalho ou mista, adjacentes ao recife. Estes ambientes são extremamente ricos e complexos no ecossistema marinho, no qual as comunidades de peixes atingem o seu maior nível de diversidade (Sale, 1991), embora esta diversidade varie conforme as regiões geográficas, abrigando cerca de 6300 espécies (Kulbicki *et al*., 2013).

No Brasil, aproximadamente 559 espécies (Carvalho-Filho e Floeter, dados não publicados) ocupam desde a interface areia/rocha e o substrato propriamente dito, até a linha d'água acima destes. Apresentam uma ampla variedade de cores, formas, hábitos tróficos, reprodutivos e inúmeras associações intra e interespecíficas. Com essa riqueza e diversidade, os peixes recifais constituem complexas comunidades nos costões rochosos. Apesar de apresentar uma menor complexidade topográfica quando comparados a recifes de corais, os costões podem abrigar uma variada fauna e flora associada.

Dentro da província biogeográfica do Brasil os ambientes de costão rochoso estão presentes principalmente no sudeste-sul do país, sendo considerados o principal habitat para biota recifal (Ferreira *et al*., 2001). Segundo Floeter *et al*., (2001) os costões rochosos dos estados do Paraná e Santa Catarina fazem parte da região sudeste do Brasil, a qual engloba os estados do Espirito Santo a Santa Catarina.

Apesar de existir uma extensa literatura sobre comunidades de peixes de costão rochoso para a costa sudeste-sul do Brasil (Hostim-Silva *et al.*, 2006; Bertoncini, 2009; Gibran e Mora, 2012; Simon *et al*., 2013), poucos destes abordam os costões do litoral do Paraná e norte de Santa Catarina (Godoy *et al*., 2007; Hackradt e Felix-Hackradt, 2009; Daros *et al.*, 2012). Locais de substratos consolidados como ilhas costeiras, costões rochosos, lajes submersas, e fundos calcários são escassos nesta faixa do sul brasileiro o que faz destes ambientes pontos de extrema importância ecológica para o ecossistema marinho, oferecendo a disponibilidade de habitats apropriados ao desenvolvimento de comunidades com características recifais. O estudo teve como objetivo i) classificar as espécies observadas com relação as categorias tróficas e suas distribuições geográficas e ii) avaliar a estrutura da comunidade de peixes de costão rochoso de ilhas costeiras no litoral sul do Brasil, comparando a densidade, biomassa e distinção taxonômica entre as ilhas amostradas.

Metodologia

Área de Estudo

O trabalho foi desenvolvido nas ilhas do litoral do estado do Paraná e no litoral norte do estado de Santa Catarina (Figura 1). No Paraná o estudo foi realizado em dois locais: no Arquipélago de Currais (25º44'S e 48º22'W), composto por três ilhas distantes cerca de 11 km da costa, com profundidades entre 1,5 a 16 metros; e na Ilha de Itacolomis (25º50'S e 48º24'W) formada por dois rochedos, localizados a 13 km da costa, com profundidade variando de 3 a 17 metros em seu entorno. As ilhas estão distantes aproximadamente 13 km uma da outra. Em Santa Catarina, o Arquipélago das Graças (26º10'S e 48º29'W) é formado por cinco ilhas e seis lajes, distante cerca de 3,5km da costa e aproximadamente 37 km da Ilha de Itacolomis. Dentro do arquipélago o trabalho foi realizado nas ilhas da Paz, Pirata, Veado e Velha e na laje da Baleia. A profundidade entorno do arquipélago varia de 1,5 a 18 metros. Os costões rochosos das ilhas possuem uma declividade moderada, entre 45º e 60º, formados principalmente por blocos e matacões (< 1 m de diâmetro). Apenas a Laje da Baleia possui uma maior proporção de matacões maiores que 1 m de diâmetro, e cobertos por macroalgas, *Palythoa* sp. e *Zoanthus* sp.

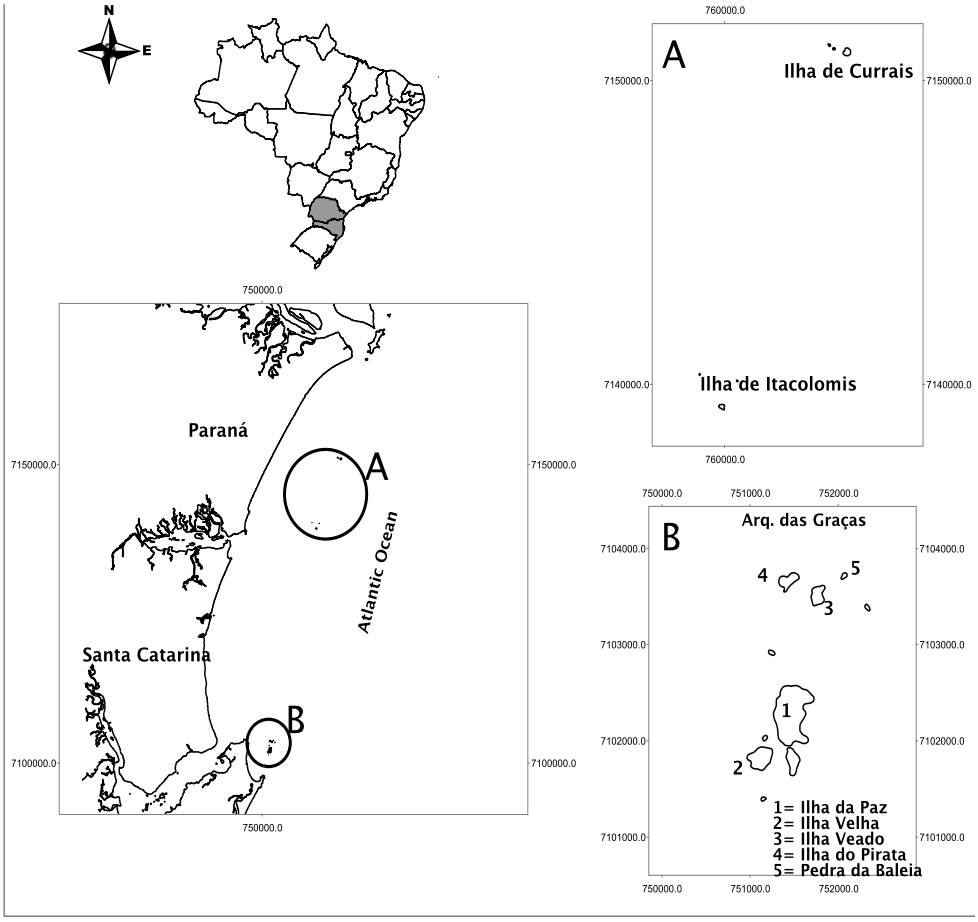

Figura 1– Mapa localizando das ilhas amostradas nos estados do Paraná e Santa Catarina. Imagens retirada do Google Earth.

Obtenção dos Dados

Os dados foram obtidos através de censo visual subaquático, utilizando a técnica de transecção-em-faixa (TF) de 40 m^2 (20 x 2 m) (ver Floeter *et al*., 2007), sendo adotada como unidade amostral. Os censos foram realizados entre outubro de 2008 e janeiro de 2010, no período das 07:00 às 15:00 h para evitar variação comportamental das espécies (Willis *et al*., 2003). As transecções em faixa foram realizadas na profundidade média de 6 metros, utilizando técnicas de mergulho autônomo como ferramenta para acessar o ambiente.

As espécies foram identificadas com o auxilio de guias de identificação e descrição fornecidos por Figueiredo e Menezes (1980), Menezes e Figueiredo (1980, 1985), Randall (1996), Humann e Deloach (2002), Hostim-Silva *et al*. (2006) e Craig e Hastings (2007). Durante as transecções em faixa além da identificação das

espécies, foram obtidos dados de densidade (indivíduos/40 m^2) e comprimento total estimado (em quatro classes: menor que 10 cm; entre 11 e 20 cm; entre 21 e 30 cm; maior que 30 cm). Utilizando os dados de comprimento total estimado, foi calculada a biomassa (gramas/40 m^2), utilizando como referencia curvas de relação peso-comprimento de cada espécie, onde os coeficientes foram obtidos em Froese e Pauly (2011), ou quando não existente, para o espécime mais próximo do gênero. Para a conversão, foram utilizados os valores médios de cada classe de comprimento(e.g. classe 21-30 = 25 cm).

Categoria trófica

Os peixes de costão rochoso observados ao longo do estudo foram agrupados em oito categorias tróficas avaliados através da literatura (Ferreira *et al*., 2004; Randall, 1967; Opitz, 1996; Floeter *et al*., 2004, 2006), em: Carnívoro (CAR); Herbívoro Móvel (HMO); Herbívoro Territorial (HTER); Onívoro (ONI); Predador de Invertebrado Móvel (PIM); Predador de Invertebrado Séssil (PIS); Piscívoro (PISC); Planctívoro (PLA).

Distribuição Geográfica

Distribuição zoogeográfica das espécies foram classificadas seguindo Luiz-Jr *et al*. (2008) em: Província Brasileira; Atlântico Central (Ilhas de St. Helena e Ascension); Circumtropical; Atlântico Leste; Patagônia (ocorrem principalmente no recifes rochosos temperados ao sul da Argentina); Sul do Caribe (costa da Venezuela, Trinidad e Tobago e outras ilhas baixo das Antilhas Lesser); Sudeste do Brasil (endêmica da região que engloba 20° a 27° S); Transatlântico (em ambos os lados do Oceano); Atlântico Ocidental (no oeste do Atlântico Norte e Sul); Caribe; Atlântico Sul; Atlântico Noroeste (Açores).

Análise dos Dados

Para verificar a existência de diferenças na estrutura taxonômica entre os locais foram calculados os índices de Distinção Taxonômica Média (AvTD, Δ^+) e da Variação na Distinção Taxonômica (VarTD, Λ^+) sendo:

AvTD ou $\Delta+ = (\Sigma\Sigma i<j\ \omega ij)/(S(S-1)/2)$,

VarTD ou $\Lambda+ = \Sigma\Sigma i<j(\omega ij - \Delta+)2/(S(S-1)/2)$,

onde xi é a quantidade de espécies i; $n = \Sigma i\ xi$, é o número total de espécies i na área de estudo; ωij é a o grau de distinção dada pelo comprimento do percurso de ligação das espécies *i* e *j* em uma árvore hierárquica; *S* é o número total de espécies de peixes por amostra (Xiujuan et al., 2010). A lista hierárquica associada com a matriz de dados foi utilizada para calcular os valores de Δ+ Λ+, construída a partir das 73 espécies observadas e agrupadas taxonomicamente seguindo Nelson (2006). O peso dado para o calculo de ωij foi ponderado e igual a 1 para todas as distâncias entre os níveis taxonômicos (Clarke e Warwick, 1999).

As comparações de densidade (indivíduos/40m^2), biomassa (g/40m^2), AvTD, VarTD e guildas tróficas entre os locais (fator fixo) foram realizadas através de análise de variância não-paramétrica Kurskal Wallis, através do pacote agricolae (Mendiburu, 2013). As análises foram realizadas no software PRIMER 6 e no ambiente R.

Resultados

No Arquipélago de Currais e na Ilha de Itacolomis foram realizados 168 TF em cada. Nas Ilhas da Paz, Pirata e Velha foram 48 TF por ilha e na Pedra da Baleia e na Ilha dos Veados foram 23 TF em cada área, totalizando 526 TF.

No total foram observados 19.377 peixes de 73 espécies, distribuídos em 34 Famílias, 8 Ordens e 2 Classes. A Ilha de Itacolomis foi o local com maior número de espécies, 51, seguido do Arq. de Currais (49), Ilha do Pirata (37), Ilhas da Paz e Velha (ambas com 34), Ilha da Baleia (31) e Ilha do Veado com 27 espécies. As famílias Blenniidae e Carangidae apresentaram seis espécies cada, seguida pelas famílias Epinephelidae, Haemulidae, Pomacentridae e Scaridae com cinco espécies cada. Considerando as 526 transeções em faixa as espécies *Stegastes fuscus, Malacoctenus delalandii, Parablennius marmoreus* e *Abudefduf saxatilis* foram às espécies com maior frequência de ocorrência (92,59%, 85,74%, 51,52%, 46,96% respectivamente). Em relação à densidade, *S. fuscus* (9,56 ind./40m^2), *A. saxatilis* (6,13 ind./40m^2), *Haemulon aurolineatum* (4,98 ind./40m^2) e *M. delalandii* (4,46 ind./40m^2) foram às espécies mais abundantes. As espécies *Acanthurus chirurgus* (534,22 g/40m^2), *S.*

fuscus (216,33 g/40m^2), *Kyphosus* spp. (195,55 g/40m^2), *Diplodus argenteus* (103,24 g/40m^2) e *Anisotremus virginicus* (100,47 g/40m^2) apresentaram a maior biomassa estimada (Tabela 1).

Tabela 1. Densidade média (Den = número de indivíduos/40m^2), Biomassa média (Bio = grama/40 m^2) e Categoria Trófica (Cat. Trof). das espécies observadas em costão rochoso no sul do BrasilCAR = carnívoro; HMO = herbívoro móvel; HTER = herbívoro territorial; ONI = onívoro; PIM = predador de invertebrado móvel; PIS = predador de invertebrado séssil; PISC = piscívoro; PLA = planctívoro. Distribuição Geográfica (Dis. Geo.): BR = Província Brasileira; CA = Atlântico Central (Ilhas de St. Helena e Ascension); CT = Cincumtropical; AL = Atlântico Leste; PT = Patagônia (ocorrem principalmente no recifes rochosos temperados ao sul da Argentina); SC = Sul do Caribe (costa da Venezuela, Trinidad e Tobago e outras ilhas baixo das Antilhas Lesser); SB = Sudeste do Brasil (endêmica da região que engloba 20° a 27° S); TA = Transatlântico (em ambos os lados do Oceano); AO = Atlântico Ocidental (no oeste do Atlântico Norte e Sul); CR = Caribe; AS = Atlântico Sul; AN = Atlântico Noroeste (Açores). * espécies apenas observadas. ✗ dados obtidos de Daros et al. (2012).

Lista de Espécies	Cat. Trof.	Dis. Geo.	Currais ✘ Den	Currais ✘ Bio	Itacolomis ✘ Den	Itacolomis ✘ Bio	Baleia Den	Baleia Bio	Paz Den	Paz Bio	Pirata Den	Pirata Bio	Veado Den	Veado Bio	Velha Den	Velha Bio
Chondrichthyes																
Myliobatiformes																
Myliobatidae																
Aetobatus narinari (Euphrasen, 1790)	CAR	CT			0,60	5,2493										
Actinopterygii																
Anguilliformes																
Muraenidae																
Gymnothorax funebris Ranzani, 1839	CAR	AO	0,60	0,9561	0,12	1,9123			0,28	3,3465						
Gymnothorax moringa (Cuvier, 1829)	CAR	AO+CA	0,30	4,1971	0,12	1,6789										
Gymnothorax vicinus (Castelnau, 1855)	CAR	TA	0,60	0,7424	0,24	2,9699										
Ophichthidae																
Myrichthys breviceps (Richardson, 1848)	PIM	AO	0,60	0,7424												
Clupeiformes																
Clupeidae																
Harengula clupeola (Cuvier, 1829)	PLA	AO					4,35	4,3183			2,83	2,6917				
Aulopiformes																
Synodontidae																
Synodus synodus (Linnaeus, 1758)	PISC	TA				*										
Beryciformes																
Holocentridae																
Holocentrus adscensionis (Osbeck, 1765)	PIM	TA	0,15	32,3742	0,45	68,2711	0,52	181,6600	0,29	35,5731	0,28	32,2888	0,43	1,4243	0,63	4,6492
Gasterosteiformes																
Syngnathidae																
Micrognathus crinitus (Jenyns, 1842)	PIM	AO	0,60	0,5357												
Pseudophallus mindii (Meek & Hildebrand, 1923)	PIM	CR+AS							0,42	0,3750			0,43	0,3913		
Fistulariidae																
Fistularia tabacaria Linnaeus,1758	PISC	TA	0,60	0,6364												
Scorpaeniformes																
Dactylopteridae																
Dactylopterus volitans (Linnaeus, 1758)	PIM	TA		*												
Scorpaenidae																
Scorpaena brasiliensis Cuvier, 1829	CAR	AO			0,12	1,9425					0,28	1,4944				
Perciformes																
Serranidae																
Diplectrum radiale (Quoy & Gaimand, 1824)	CAR	AO	0,60	0,8869											0,28	0,3142
Serranus flaviventris (Cuvier ,1829)	PIM	AO	0,65	7,6336	0,33	11,6978	0,13	0,2657	0,33	11,6978	0,90	33,4479	3,43	56,2435	1,35	21,1233
Epinephelidae																
Epinephelus marginatus (Lowe, 1834)	CAR	SB+PT+AL	0,42	17,1429	0,95	66,4229	0,43	33,6743	0,83	4,1578	0,13	6,3498	0,34	96,9922	0,28	1,5833
Epinephelus morio (Valenciennes, 1828)	CAR	AO		*												
Hyporthodus niveatus (Valenciennes, 1828)	CAR	AO	0,60	0,1554	0,24	0,6222							0,13	0,3487		
Mycteroperca acurtirostris (Valenciennes, 1828)	PISC	AO	0,22	36,1887	0,83	4,1885	0,22	31,6243	0,14	5,8125	0,28	45,4625	0,22	6,4696	0,25	13,6242
Mycteroperca bonaci (Poey, 1860)	PISC	AO	0,60	1,5119							0,28	3,6754				

Continua

Lista de Espécies	Cat. Trof.	Dis. Geo.	Currais ✘		Itacolomis ✘		Baleia		Paz		Pirata		Veado		Velha	
			Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio
Priacanthus arenatus Cuvier, 1829	CAR	TA													0,63	46,3313
Carangidae																
Carangoides crysos (Mitchill, 1815)	PISC	TA	0,60	0,3625	0,36	6,9154										
Caranx latus Agassiz, 1831	PISC	TA			0,60	0,5511										
Chloroscombrus chysurus (Linnaeus,1766)	PLA	TA	0,48	3,5758	0,12	4,8195	1,35	44,3952			0,19	6,5788	1,35	47,2987	0,28	2,9181
Pseudocaranx dentex (Bloch & Schemeider, 1801)	PLA	CT	0,68	73,1554	0,29	29,9796					0,42	12,2240				
Selene setapinnis (Mitchill, 1815)	CAR	AO					0,43	17,6000								
Selene vomer (Linnaeus, 1758)	PISC	AO			0,60	0,3273										
Lutjanidae																
Lutjanus analis (Cuvier, 1828)	CAR	AO	0,12	0,3518												
Haemulidae																
Anisotremus surinamensis (Bloch, 1791)	PIM	AO	0,17	46,5353	0,18	17,4977	1,48	143,1987	0,19	16,3579	0,28	11,9796	0,87	16,6378		
Anisotremus virginicus (Linnaeus, 1758)	PIM	AO	0,84	71,9563	0,61	64,7427	1,27	33,8617	1,17	177,2619	2,23	26,2240	1,43	46,1513	0,81	71,2978
Haemulon aurolineatun Cuvier, 1830	PIM	AO	1,39	117,3993	4,67	42,7836	0,17	1,3870	0,50	0,8731	0,14	1,3794	0,83	18,9378	0,79	51,1398
Haemulon steindachneri (Jordan & Gilbert, 1882)	PIM	AO	0,30	1,3333	0,60	0,6140	0,43	0,1835			0,81	46,7128	0,52	51,9596	0,54	47,6383
Orthopristis ruber Cuvier, 1830	PIM	AO	0,14	1,3712	0,24	0,3851	0,43	1,9652	0,83	0,1842	0,48	3,7450	0,78	1,7283	0,44	0,9664
Sparidae																
Archosargus probatocephalus (Walbaum, 1792)	ONI	AO			0,60	2,1560					0,28	7,3678	0,43	18,6770		
Archosargus rhomboidalis (Linnaeus, 1758)	ONI	AO					0,43	2,8387								
Diplodus argenteus (Valenciannes, 1830)	ONI	AO	0,14	11,7328	0,27	76,6417	2,91	948,7774	1,65	132,1681	2,44	227,9690			0,13	9,2998
Sciaenidae																
Odontoscion dentex (Cuvier, 1830)	CAR	AO	2,27	6,7256	2,15	81,3383	1,17	37,8591	1,78	36,5890	3,28	91,4875	3,27	26,4522	0,90	46,6400
Pareques acuminatus (Bloch & Schemeider, 1801)	PIM	AO	0,40	1,8754	0,46	15,3436	0,91	74,2374	0,31	13,8528	0,25	5,5528	0,48	24,8227	0,15	4,3228
Mullidae																
Pseudupeneus maculatus (Bloch, 1793)	PIM	AO	0,27	18,9393	0,11	8,8649			0,25	28,3250	0,28	6,5119			0,31	22,3642
Pempheridae																
Pempheris schomburgkii Muller & Trschel,1848	PLA	AO	0,36	1,2552	0,65	1,4386										
Kyphosidae																
Kyphosus sp.	HMO	TA	0,60	15,3000	0,77	563,1875	0,43	0,9696			0,48	118,7675				
Chaetodontidae																
Chaetodon striatus Linnaeus, 1758	PIS	AO	0,57	36,4987	0,15	9,3899	0,17	12,2469	0,48	2,2665	0,38	18,4229	0,27	2,3827	1,13	39,2592
Pomacanthidae																
Pomacantus paru (Bloch, 1787)	ONI	AO	0,40	41,3239	0,46	1,1486	0,91		0,31	64,3631	0,25		0,48		0,15	
Pomacentridae																
Abudefduf saxatilis (Linnaeus, 1758)	ONI	CT	4,74	24,5274	11,29	7,9395	2,65	73,9783	2,94	53,3773	5,00	226,9578	2,34	12,4652	0,73	21,5965
Chromis multilineata (Guichenot, 1853)	PLA	TA			0,12	0,2827							0,35	2,6391	0,42	0,9167
Stegastes fuscus (Cuvier, 1830)	HTER	BR	9,54	197,4625	14,33	338,3413	3,96	96,8970	3,69	5,4828	2,78	83,5269	18,39	31,3296	5,78	166,4146
Stegastes pictus (Castelnau, 1855)	HTER	BR+SC		*												
Stegastes variabilis (Castelnau, 1855)	HTER	AO	0,24	0,9199	0,24	0,5722	0,22	0,5227	0,83	0,2417	0,23	8,9917				
Labridae																
Bodianus rufus (Linnaeus, 1758)	PIM	AO			0,24	2,2693										
Halicoeres poeyi (Steindachner, 1867)	PIM	AO	0,36	1,3693	0,12	1,3557					0,28	0,9525			0,63	1,9354

Continua

Lista de Espécies	Cat. Trof.	Dis. Geo.	Currais ✘		Itacolomis ✘		Baleia		Paz		Pirata		Veado		Velha	
			Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio	Den	Bio
Scaridae																
Cryptotomus roseus Cope, 1871	HMO	AO							0,28	1,1550						
Sparisoma amplum (Ranzani, 1841)	HMO	BR			0,60	1,8479			0,42	12,9350	0,63	19,4250				
Sparisoma axilaris (Steindachner, 1878)	HMO	BR	0,65	27,8695	0,54	53,1242	0,87	166,9643	0,63	12,9790					0,14	32,3375
Sparisoma frondosus (Agassiz, 1831)	HMO	BR+SC	0,30	7,4399	0,24	15,5448					0,42	7,7948	0,43	2,7743	0,28	6,4675
Sparisoma radians (Valenciennes, 1840)	HMO	AO			0,60	0,9448										
Blenniidae																
Hypleurochilus fissicornis (Quoy & Gaimard, 1824)	PIM	AS+AN.							0,42	0,7833	0,83	2,2783			0,42	0,7833
Hypsoblennius invermar Smith-Vaniz & Acero-P., 1980	ONI	AO			0,18	0,6377	0,43	0,5870	0,83	0,1128					0,28	0,2813
Ophioblennius trinitatis Miranda Ribeiro, 1919	HTER	BR			0,60	0,9345										
Parablennius marmoreus (Poey, 1876)	ONI	AO	0,72	1,2239	1,82	3,9500	1,48	2,5117	0,40	0,6728	1,78	2,9292	1,13	1,9200	0,46	0,7788
Parablennius pilicornis (Cuvier, 1829)	ONI	TA	0,48	0,8952	0,28	1,3396	1,57	13,4583	0,83	0,1417	0,29	2,2242	0,17	0,2957	0,17	0,2833
Scartela cristata (Linnaeus, 1758)	ONI	CT	0,24	0,3732	0,30	0,4667	0,13	2,6117								
Labrisomidae																
Labrisomus nuchipinnis (Quoy & Gaimand, 1824)	CAR	TA	0,12	0,1726	0,12	3,8395	0,13	4,3000	0,83	3,7563	0,33	5,4778			0,28	0,3283
Malacoctenus delalandii (Valemciennes, 1836)	PIM	AO	2,17	3,1760	7,87	12,5122	5,69	7,8917	3,28	4,2563	4,83	7,1854	2,87	1,4483	3,19	5,2500
Paraclinus spectator Guimarães & Bacellar, 2002	PIM	BR	0,18	0,3671									0,43	0,8783	0,28	0,4283
Gobiidae																
Coryphopterus glaucofraenum Gill, 1863	PLA	AO	2,71	3,3229	0,15	0,1896			0,33	0,4854	1,14	2,7265	5,70	6,9787	4,15	5,7979
Ephippidae																
Chaetodpterus faber (Broussonet, 1782)	ONI	AO	0,30	13,7240			0,27	48,9569	0,42	75,3928	0,17	29,5528	0,87	6,3687		
Acanthuridae																
Acanthurus bahianus Castelnau, 1855	HMO	AO	0,60	0,5857					0,28	1,2856	0,42	11,1392				
Acanthurus chirugus (Bloch,1787)	HMO	TA	0,30	1,9944	1,95	1.649,1467	0,87	85,8596	0,63	2,8479	0,83	24,9456			0,28	6,2365
Acanthurus coeruleus Bloch & Schneider, 1801	HMO	AO				*										
Scombridae																
Scomberomorus brasiliensis Collete, Russo & Zavala-Camin,	PISC	AO			0,12	4,5827										
Tetraodontiformes																
Monacanthidae																
Stephanolepis hispidus (Linnaeus, 1766)	ONI	TA	0,60	1,3578	0,60	1,3578	0,13	19,9713	0,28	1,2478					0,28	4,7498
Tetraodontidae																
Sphoeroides spengleri (Bloch, 1785)	PIS	AO	0,21	6,4198	0,60	2,2759			0,28	0,6625	0,17	9,6585	0,27	19,8843	0,28	4,5133
Sphoeroides testudineus (Linnaeus, 1758)	PIM	AO													0,28	1,6454

Distribuição Geográfica

Das espécies observadas, aproximadamente 60% (44) das espécies ocorrem no Atlântico Ocidental, 19,18% (15) são Transatlânticas e cerca de 10% (7) são endêmicas do Brasil. Espécies que ocorrem na região Circumtropical, no Atlântico Sul e no Sul do Caribe contribuem com 5,48% (4), 2,74% (2), 2,74% (2) respectivamente (Figura 2).

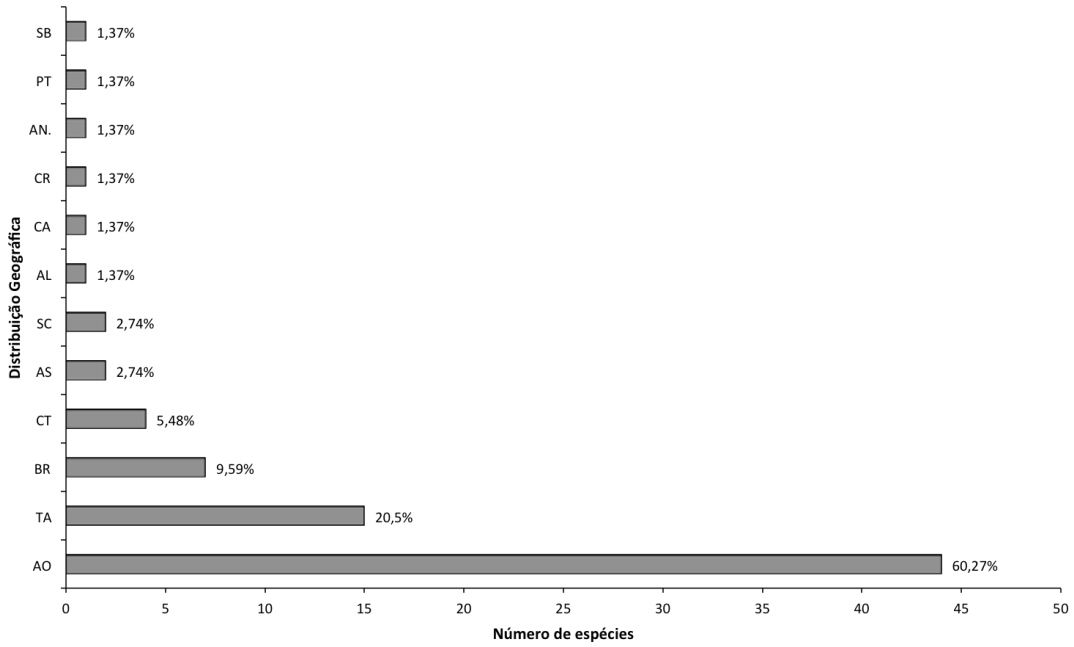

Figura 2. Número de espécie e porcentagem por distribuição geográfica das espécies observadas em costão rochoso no sul do Brasil. BR = Província Brasileira; CA = Atlântico Central (Ilhas de St. Helena e Ascension); CT = Cincumtropical; AL = Atlântico Leste; PT = Patagônia (ocorrem principalmente nos recifes rochosos temperados ao sul da Argentina); SC = Sul do Caribe (costa da Venezuela, Trinidad e Tobago e outras ilhas baixo das Antilhas Lesser); SB = Sudeste do Brasil (endêmica da região que engloba 20° a 27° S); TA = Transatlântico (em ambos os lados do Oceano); AO = Atlântico Ocidental (no oeste do Atlântico Norte e Sul); CR = Caribe; AS = Atlântico Sul; AN = Atlântico Noroeste (Açores).

Categoria Trófica

Das 73 espécies observadas, agrupadas em oito categorias tróficas, 26% (19 espécies) são predadores de invertebrados móveis (PIM). Carnívoro (CAR) foi à segunda categoria em número de espécie com 14, representando 19,18% do total das observadas. As demais categorias, onívoro (ONI), herbívoro móvel (HMO), piscívoro

(PISC), planctívoro (PLA), herbívoro territorial (HTE) e predador de invertebrado séssil (PIS) juntas contribuíram com 40% do número de espécies (11, 9, 8,7,4 e 2 respectivamente).

Considerando o total de peixes contabilizados, PIM foi a categoria trófica que apresentou a maior densidade, 12,57 ind./40m^2, seguido das categorias HTER e ONI com 9,61 e 8,25 ind./40m^2. Com relação a biomassa, HMO foi a categoria que representou a maior biomassa geral, 780,48 g/40m^2, seguido por PIM (300,57 g/40m^2), HTER (217,42 g/40m^2) e ONI (217, 41 g/40m^2).

Aproximadamente 32%da densidade total para a Pedra da Baleia é composta por espécies consideradas PIM, seguido por ONI (29,12%), PLA (17,99%) e HTER (13,19%). A soma das demais categorias representou7,55%. No Arq. de Currais, as espécies agrupadas nos grupos tróficos PIM, HTER, ONI representaram respectivamente 41,42%, 24,94% e 15,75% da densidade total enquanto que CAR, HMO, PISC, PLAe PIS, juntos representaram 17,89%. Trinta por cento da densidade total na Ilha de Itacolomis foi representada por PIM,com HTER representando 29,81% e ONI com 27,29%. Já as demais categorias concentraram 11,23%. Na Ilha da Paz, as três categorias com maior densidade total, representaram 83,37%, onde PIM contribuiu com 34,05%, ONI com 28,70% e HTER com 20,62%. As outras categorias somaram 16,63%. Na Ilha do Pirata, PIM e ONI foram as categorias tróficas que mais contribuíram na densidade total, com mais de 30% cada. Carnívoros e PLA responderam respectivamente por 11,71% e 10,85% da densidade total da ilha. Juntas, as outras categorias somaram 14,43%. Os HTER contribuíram com 42,77% na densidade total na Ilha do Veado. Já PIM e PLA representaram 20,93% e 17,19 respectivamente. Na Ilha da Velha, a categoria trófica que mais contribuiu na densidade total foi o PIM, com 35,25%, seguidos dos HTER (26,11%) e PLA (19,04%). As demais categorias juntas contribuíram com 19,60% nessa ilha (Figura 3).

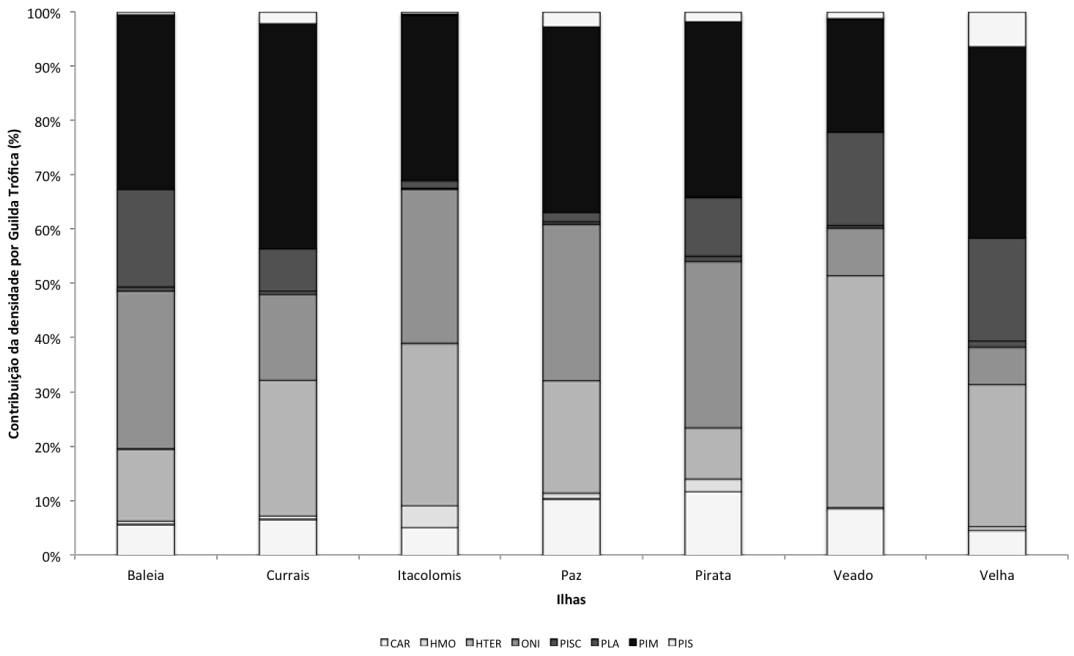

Figura 3.Contribuição em Densidade (ind./40m2) das Categorias tróficas para cada Local. CAR = carnívoro; HMO = herbívoro móvel; HTER = herbívoro territorial; ONI = onívoro; PIM = predador de invertebrado móvel; PIS = predador de invertebrado séssil; PISC = piscívoro; PLA = planctívoro.

Com relação a biomassa total, PIM foi o grupo que mais contribuiu no Arq. de Currais (31,55%)e na Ilha Velha (36,27%). Na Ilha de Itacolomis a categoria trófica HMO foi a que apresentou a maior biomassa contribuindo com 70,17% da biomassa total. Predominaram em termos de biomassa na Pedra da Baleia (48,61%), Ilha da Paz (40,55%) e Ilha do Pirata (37,26%) a categoria ONI (Figura 4).

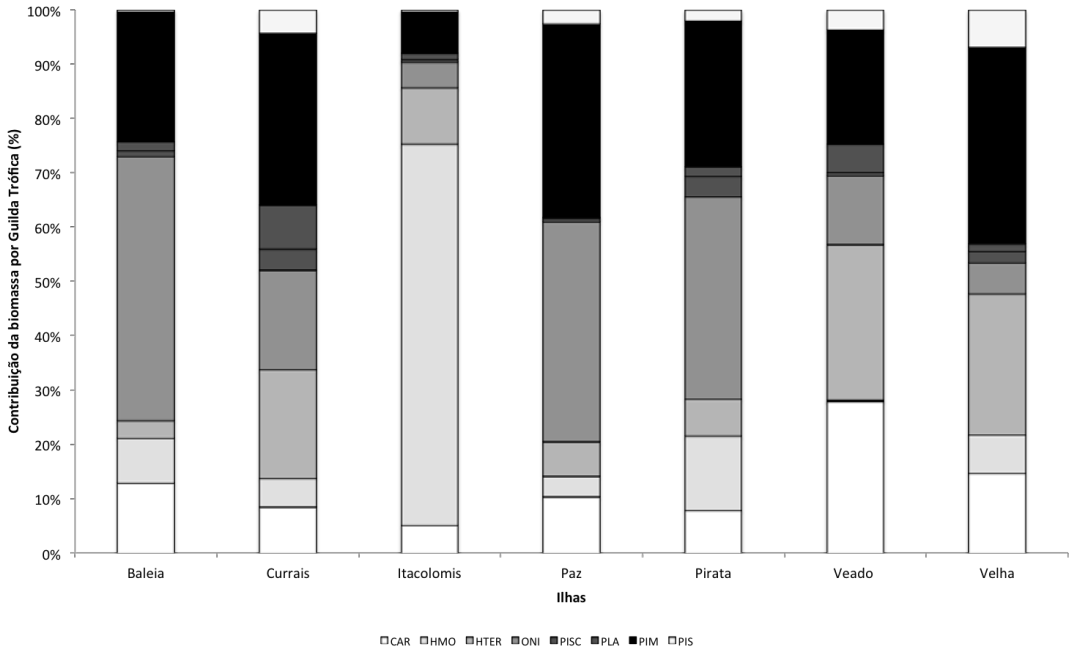

Figura 4. Contribuição em Biomassa (gramas/40m^2) das Categorias tróficas para cada Local. CAR = carnívoro; HMO = herbívoro móvel; HTER = herbívoro territorial; ONI = onívoro; PIM = predador de invertebrado móvel; PIS = predador de invertebrado séssil; PISC = piscívoro; PLA = planctívoro.

Classes de tamanho

Cerca de 26 ind/40m^2 (70% do total) possuem comprimento total menor que 10 cm. A classe de comprimento total entre 11 e 20 cm apresentou uma densidade de 9,36 ind./40m^2, aproximadamente 26%. As demais classes, entre 21 e 30 cm e maior que 30 cm de comprimento total, com densidade de 0,93 ind./40m^2 e 0,57 ind./40m^2 representaram 2,54% e 1,56% do total respectivamente. Em relação à biomassa, a classe de tamanho com indivíduos maiores de 30 cm apresentou 929,18 gramas/40m^2, representando 51,90% do total estimado. Peixes menores que 10 cm apresentaram 50,63 gramas/40m^2 representando 2,83% do total, peixes entre 11 e 20 cm 552,82 gramas/40m^2 (30,87%) e entre 21 e 30 cm apresentaram 257,59 gramas/40m^2 (14,38%).

Densidade (indivíduos/40m^2)

Com relação à densidade de peixes, o resultado da análise de variância mostrou que há diferença significativa entre os locais (x^2= 96,64; p<0,001). A maior densidade foi observada na Ilha de Itacolomis (48,18 ±2,82 ind./40 m^2), seguida pela Ilha do Veado (43 ±3,38 ind./ 40 m^2), Arq. de Currais (36,40 ±2,54 ind./ 40 m^2), Pedra da Baleia (31,65 ±4,75 ind./ 40 m^2), Ilha do Pirata (31,47 ±4,12 ind./ 40 m^2), Ilha Velha (22,10 ±1,40 ind./ 40 m^2) e Ilha da Paz (18,29 ±1,75 ind./ 40 m^2) (Figura 5).

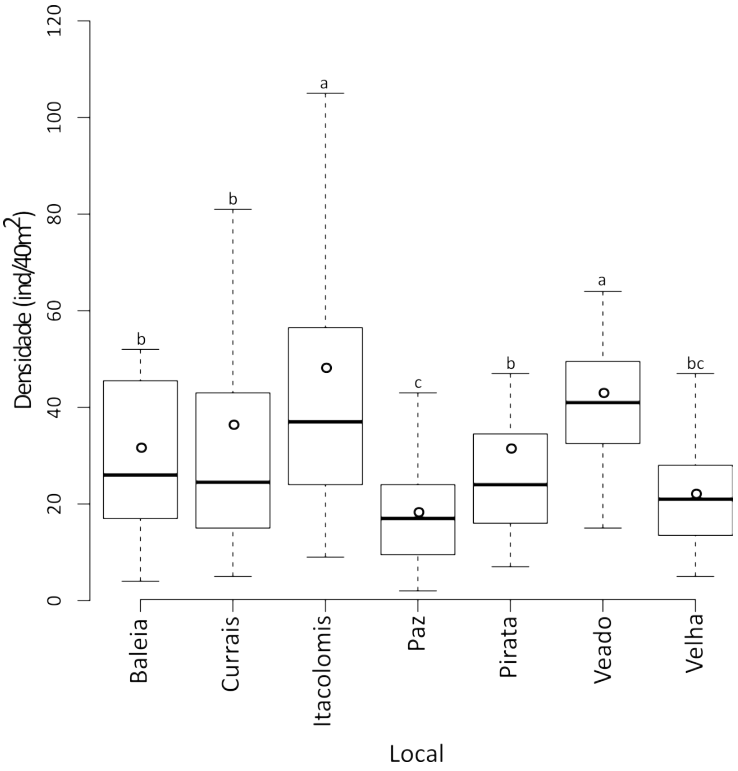

Figura 5. Densidade (ind./40 m^2) dos peixes nas ilhas estudadas. Letras iguais = densidade estatisticamente iguais.

Biomassa (gramas/40 m^2)

O resultado da análise de variância mostrou que a biomassa estimada (gramas/40m^2) foi diferente significativamente entre os locais (x^2= 30,47; p<0,001). A biomassa média foi maior na Ilha de Itacolomis(3.253,09 ±1187,25g/40 m^2) e na Pedra da Baleia (3.028,65 ±754,12 g/40 m^2),seguidas pelas ilhas do Pirata (133,58 ±259,12 g/40 m^2), Veado (1.087 ±247,24 g/40 m^2), Arq. de Currais (994,04 ±150

g/40 m^2), ilhas da Paz (836,38 ±114,84 g/40 m^2) e Velha (639,82 ±111,07 g/40 m^2) (Figura 6).

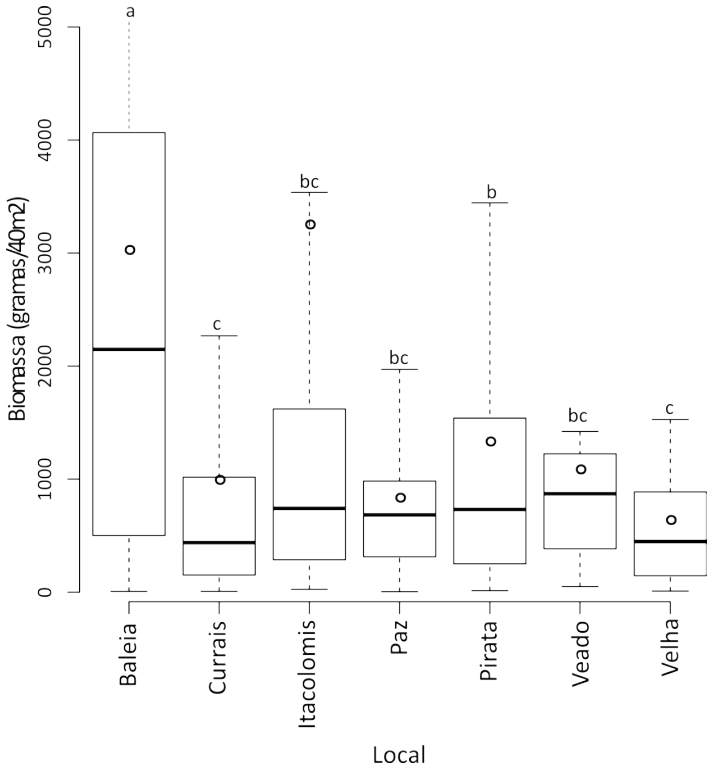

Figura 6. Biomassa estimada (gramas/40m^2) dos peixes nas ilhas estudadas. Letras iguais = densidade estatisticamente iguais.

Distinção Taxonômica

Os valores médios de AvTD para cada ilha estão muito próximos da média esperada para o índice, não apresentando diferenças significativas (x^2= 3,53; p = 0,7394), diferenciando apenas no número de espécies, onde a Ilha de Itacolomis apresentou 51 espécies, Arq. de Currais com 49, Ilha do Pirata com 37, Ilhas da Paz e Velha com 34 cada, Pedra da Baleia com 31, e Ilha da Velha com 27 (Figura 7).

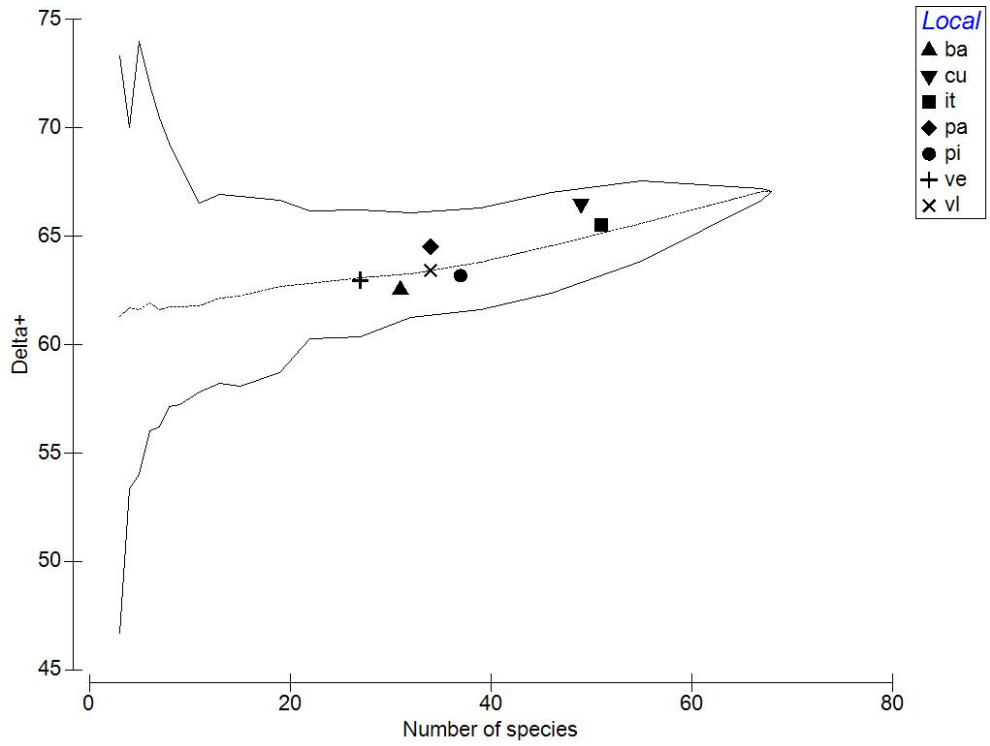

Figura 7. Distinção Taxonômica Média (Δ+) calculada para cada Local amostrado. Média esperada representa pela linha pontilhada central e intervalo de confiança (95%) representada pela linha sólida em forma de funil.ba = Pedra da Baleia; cu = Arq. de Currais; it = Ilha de Itacolomis; pa = Ilha da Paz; pi = Ilha do Pirata; ve = Ilha do Veado; vl = Ilha Velha.

O índice VarTD apresentou valores dentro do intervalo de confiança de 95%, Entretanto, diferenças significativas entre os locais ($x^2$38,58= 1,1662; p= 8,63e-07) foram registradas destacando-se a Ilha de Itacolomis que está mais afastada da média esperada para o índice, mesmo assim está dentro do intervalo de confiança de 95%. As comparações par a par entre locais na VarTD mostraram que a Pedra da Baleia, Ilha de Itacolomis, Ilha do Pirata e Ilha do Veado não diferem significativamente entre si. Os resultados do teste também mostraram que a Ilha de Itacolomis é semelhante estatisticamente à ilha da Paz, o mesmo tendo sido observado entre o Arq. de Currais, Ilha da Paz e a Ilha da Velha (Figura 8).

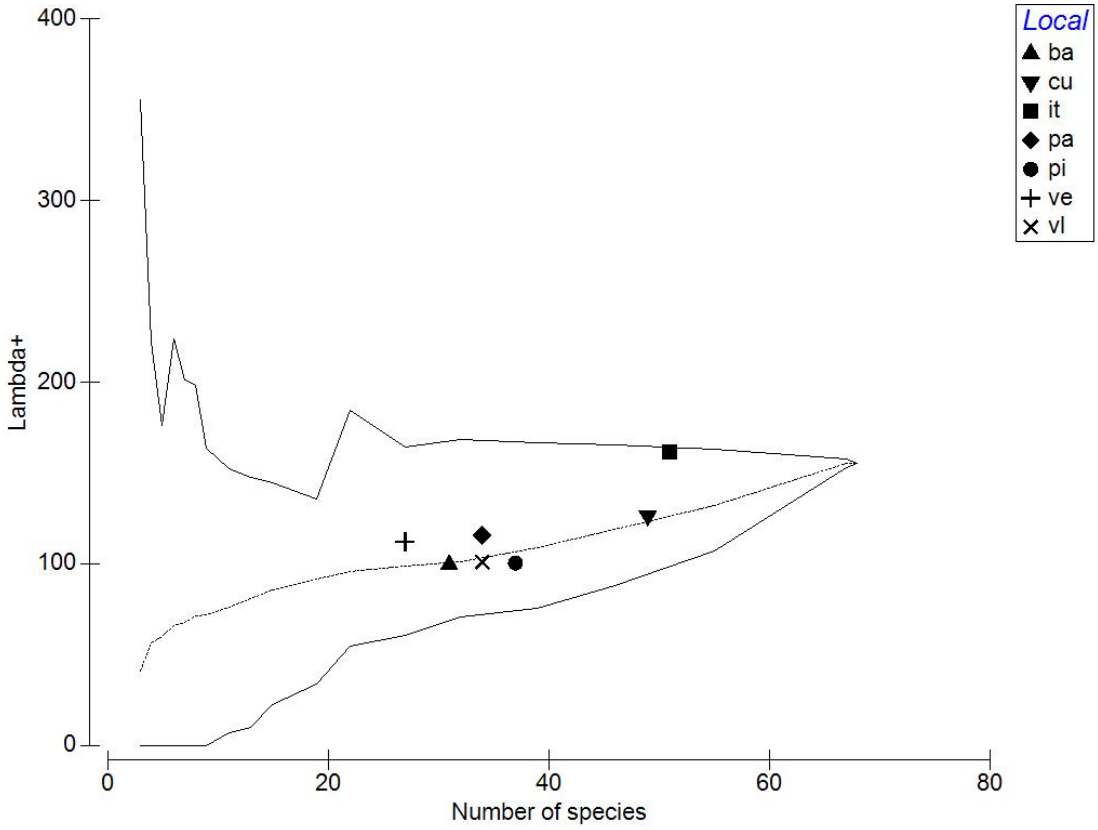

Figura 8. Variação da Distinção Taxonômica (Λ+)calculada para cada Local amostrado. Média esperada representa pela linha pontilhada central e intervalo de confiança (95%) representada pela linha sólida em forma de funil.ba = Pedra da Baleia; cu = Arq. de Currais; it = Ilha de Itacolomis; pa = Ilha da Paz; pi = Ilha do Pirata; ve = Ilha do Veado; vl = Ilha Velha.

As simulações bivariadas para AvTD e VarTD apresentam os valores de todas as áreas de coleta dentro do intervalo de confiança de 95%. O formato da elipse e da distribuição das médias sugere uma correlação positiva entre AvTD e VarTD (Figura 9).

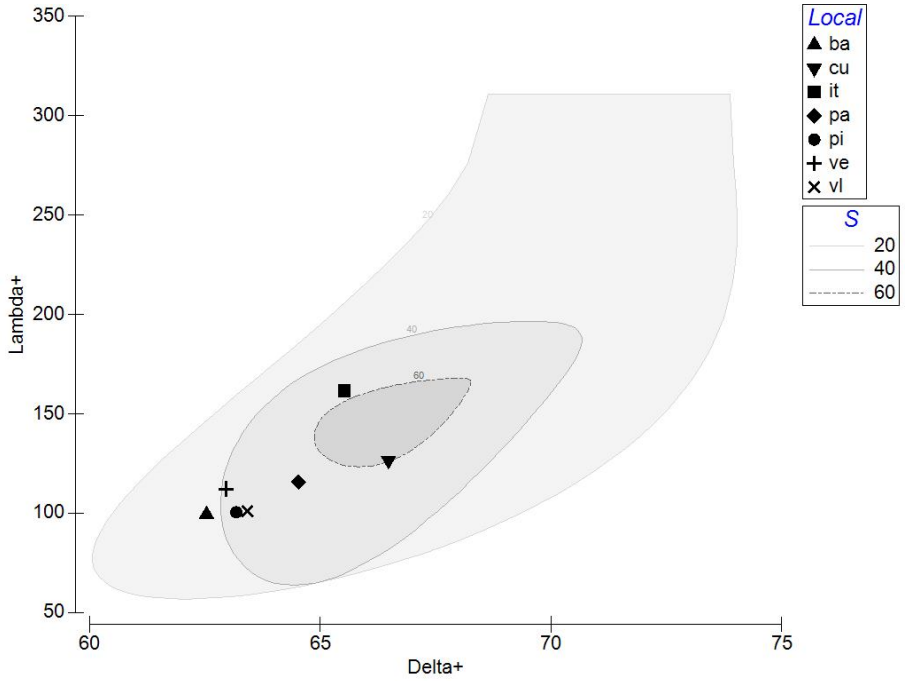

Figura 9. Distinção Taxonômica Média (Δ+) dos Locais plotados contra os correspondentes valores da Variação da Distinção Taxonômica (Λ+). Elipse representando o intervalo de confiança de 95% dos valores pareados, obtidos de 60 independentes simulações independentes(S) randomizadas. ba = Pedra da Baleia; cu = Arq. de Currais; it = Ilha de Itacolomis; pa = Ilha da Paz; pi = Ilha do Pirata; ve = Ilha do Veado; vl = Ilha Velha.

Discussão

Estudos utilizando de métodos não-destrutivos vem sendo descritos desde a década de 50 por Brock (1954), principalmente em ambientes frágeis como recifes de corais e em unidades de conservação (ROCHA *et al.,* 1998; Hostim-Silva *et al.*, 2006; Luiz-Jr *et al*., 2008). Também chamado de censo visual subaquático, esse método é utilizado em estudos em ambientes marinhos ou de água doce, na aquisição de dados de comunidade, biológicos e comportamentais da fauna e flora (Risk, 1972; Booth e Beretta, 1994; Bonaldo *et al.*, 2008), que podem ser realizados de diversas formas, como transecção em faixa (Ferreira *et al*., 2001; Mendonça-Neto *et al.*, 2008), estacionário (Colvovoresse e Acosta, 2007; Mendonça-Neto *et al.*, 2008), utilizando fotografia (Preskitt *et al.*, 2004) e sistemas de vídeo (Harvey *et al.*, 2004), de acordo com as hipóteses de pesquisa e logística disponível para cada estudo.

Neste estudo, abrangendo costões rochosos do Arquipélago de Currais, Ilha de Itacolomis e as ilhas do Arquipélago das Graças, cobrimos uma área de 21.040 m^2 através de 526 transecções-em-faixa ($40m^2$). Observamos 73 espécies, que representam 13% do total (aproximadamente 559 espécies) encontrado na costa do Brasil segundo Carvalho-Filho e Floeter (dados não publicados). Para as ilhas do Paraná Hackradt & Félix-Hackradt (2009) e Daros *et al.*, (2012) observaram 77 espécies, das quais 66% e 64% foram observadas apenas na Ilha de Itacolomis e Arquipélago de Currais, respectivamente. Godoy *et al*., (2007) realizaram censos visuais subaquáticos, utilizando a mesma metodologia deste trabalho, e apenas na Ilha da Paz observaram 33 espécies, uma a menos do que no presente levantamento. Somando o número total de espécies, o Arquipélago das Graças apresentou uma riqueza absoluta de 53 espécies.

A comparação do número de espécies com outros estudos realizados na região sudeste-sul do Brasil, na qual nossa área de estudo está inserida, (Floeter *et al*., 2001), a riqueza observada nas ilhas estudadas por nós está próxima da observada por Alves e Pinheiro (2011) nas ilhas do Balneário Barra do Sul (SC) e Mendonça-Neto *et al.*, (2008) nos costões rochosos do Rio de Janeiro. Por outro lado, estudos realizados também em costões rochosos na região sudeste-sul por Ferreira e*t al.*, (2001) (RJ), Hostim-Silva *et al.*, (2006) (SC), Floeter *et al.*, (2007) (ES), Rangel *et al.*, (2007) (RJ), Luiz-Jr *et al.*, (2008) (SP), Bertoncini (2009) (SC) e Gibran e Moura (2012) (SP), apresentaram uma maior riqueza. Essas diferenças observadas entre as áreas de estudo não estão apenas ligadas à morfologia de cada local ou à variação latitudinal, mas também ao esforço amostral empregado para obtenção dos dados, ao método de censo visual utilizado, a diferenças nas profundidades amostradas, ao uso das áreas e ao grau de proteção, além do período do ano amostrado.

Em relação ao número de espécies por família, Blenniidae, Carangidae, Haemulidae, Pomacentridae e Scaridae apresentaram maior riqueza, o mesmo tendo sido observado por Floeter *et al.*, (2001), que define estas famílias como as principais para a região sudeste/sul do Brasil. Segundo os mesmos autores, a família Serranidae é a que apresenta a maior riqueza. Craig e Hasting (2007) propuseram uma mudança na família Serranidae, promovendo a subfamília Epinephelinae à família Epinephelidae, que em nossos resultados apresentou um número significativo (5) de espécies.

A assembleia de peixes de costão rochoso observada em nosso estudo é formada principalmente por espécies que ocorrem no Atlântico Ocidental e Nordeste Brasileiro. Esta distribuição ocorre, principalmente, pela influencia da Corrente do Brasil, de águas quentes e superficial, transportando larvas de peixes tropicais até o litoral de Santa Catarina, que segundo Floeter *et al*., (2008) é o limite sul da distribuição de peixes recifais no Brasil.

A categorização trófica, baseada no principal item alimentar, é uma ferramenta útil pois agrupa taxonômicos, podendo inferir atributos ecológicos como disponibilidade de alimento e uso dos recursos (Bellwood *et al*., 2002). Considerando as espécies agrupadas em categorias tróficas, predadores de invertebrados móveis (PIM) foi a categoria que apresentou a maior riqueza de espécie, seguida pelos dos carnívoros (CAR) e onívoros (ONI). Segundo Ferreira *et al.*, (2004) a dominância destes grupos em regiões subtropicais é resultado da diminuição de herbívoros móveis (ex. Famílias Acanthuridae e Scaridae), que possuem uma maior dominância em regiões de baixa latitudes.

Descritos como o principal grupo trófico em ambientes recifais (Wainwright e Bellwood, 2002) devido a grande quantidade e alimento disponível em substratos consolidados e inconsolidados (Harmelin e Vivien, 2002), PIM apresentaram também a maior densidade (peixes/40m^2). *Malacoctenus delalandii* e *Haemulon aurolineatun* foram as espécies que apresentaram a maior densidade dentro do grupo. Com relação a biomassa (gramas/40m^2), na categoria PIM, três espécies da família Haemulidae foram as mais representativas (*Anisotremus virginicus*, *H. aurolineatun* e *H. steindachneri*).

Em termos de densidade e biomassa *Odontoscion dentex* foi o principal representante da categoria CAR na área de estudo. Esse resultado difere do observado na região SE, onde espécies da família Serranidae foram as mais abundantes (Ferreira *et al.*, 2004). Chaves & Monteiro-Neto (2009), observaram que *Labrisomus nuchipinnis* foi o mais abundante entre os carnívoros, atribuindo a baixa abundância dos Serranídeos à histórica pressão pesqueira na costa do Rio de Janeiro. A baixa presença dos Serranídeos nas ilhas pode estar relacionada com o grande esforço de pesca sobre o recurso, alvo da pesca comercial e amadora nos costões rochosos da região (Medeiros *et al*., 1997; Gerhardinger *et al*., 2006) .

Onívoro (ONI) foi o grupo que apresentou a terceira maior densidade, divergindo do observado na costa fluminense, onde foi a mais abundante (Ferreira *et al*., 2004; Chaves e Monteiro-Neto, 2009). As espécies *Abudefduf saxatilis* e *Diplodus argenteus* foram as principais, tanto em densidade como em biomassa. Ambas possuem uma grande plasticidade, habitando diferentes ambientes recifais e alimentando-se de uma variada gama de recursos (Carvalho-Filho, 1999; Ferreira *et al*., 2004; Harmelin-Vivien, 2002).

Segundo Ferreira *et al.*, (2004), *Stegastes fuscus* é a espécie herbívora territorialista mais abundante dos recifes de Pernambuco até os costões rochosos do litoral centro norte de Santa Catarina. A espécie foi a mais frequente, mais abundante e a segunda em termos de biomassa em nosso estudo. Já a categoria herbívoro móvel (HMO), considerada como de menor abundância na região SE quando comparada ao N e NE do Brasil, foi a que apresentou a maior biomassa, principalmente pela presença das espécies *Acanthurus chirurgus* e *Kyphosus* spp.. Ferreira *et al.*, (2004) comparando latitudinalmente as categorias tróficas, mostram que Acanthuridae é mais abundante até Arraial do Cabo e Kyphosidae dominam o nicho em Santa Catarina. A lacuna geográfica preenchida por esse estudo, mostra que na verdade, com um esforço amostral adequado, espécies como *A. chirurgus* podem ter uma contribuição relativa maior do que o sugerido por Ferreira *et al.*, (2004) para os recifes mais ao sul. Os dados deste estudo, para os herbívoros, concordam com Floeter *et al.*, (2005) que descrevem uma diminuição da riqueza e abundância em direção as altas latitudes, e a substituição de herbívoros móveis por territorialistas.

As demais categorias, piscívoros (PISC), planctívoros (PLA) e predadores de invertebrados sésseis (PIS) apresentaram uma baixa densidade e biomassa com relação as demais. As principais espécies foram: *Mycteroperca acutirostris* (PISC), *Coryphopterus glaucofraenum* e *Harengula clupeola* (PLA) e *Chaetodon striatus* (PIS). Alguns estudos (ex. Floeter *et al.*, 2007; Rangel *et al.*, 2002; Chaves e Monteiro-Neto, 2009) mostram uma baixa riqueza e abundância de PLA na costa, sendo as maiores abundâncias encontradas nas ilhas oceânicas (Ferreira *et al.*, 2004).

A grande maioria dos indivíduos observados apresentou tamanhos menores que 10 cm. Esse resultado já era esperado, tendo em vista que a maioria das espécies observadas neste estudo apresentam seus comprimentos máximos próximos a 10 centímetros. Outro fator é a migração ontogenética de algumas espécies, como *E.*

marginatus (Machado *et al.*, 2003), onde os indivíduos menores se encontram em locais mais rasos que os maiores, que procuram refúgios em locais mais profundos, diminuindo assim a competição por espaço e alimento.

Como forma de facilitar as comparações entre regiões e entre número de amostragens diferentes, a densidade vem sendo utilizada como medida de abundância e biomassa por área amostrada. Em nosso estudo as amostras possuem $40m^2$, que é facilmente convertida e comparável com qualquer outra unidade de medida. Com relação ao número de peixes por $40m^2$, a Ilha de Itacolomis apresentou a maior densidade, porém estatisticamente semelhante a Ilha do Veado. Pedra da Baleia, Arq. de Currais, Ilha do Pirata e Ilha da Velha não apresentam diferenças significativas em suas densidades. A Ilha da Paz foi o local com menor densidade. Com relação a biomassa por área, também houve diferença entre os locais, onde a Ilha de Itacolomis e a Pedra da Baleia apresentaram a maior biomassa por área. Essas diferenças entre o número de peixes e biomassa por área pode estar relacionada com diversos fatores, entre estes, complexidade (Bell *et al*., 1991; Friedlander *et al*., 2003), cobertura do substrato (Luiz-Jr., 2009; Krajewski e Floeter, 2011) e grau de exposição às ondas (Floeter *et al*., 2007).

A utilização e combinação do AvTD e VarTD pode proporcionar um resumo robusto dos padrões de parentescos taxonômicos dentro da assembleia (Clarke & Warwick, 2001) baseando-se na uniformidade de distribuição de táxons em uma árvore taxonômica hierárquica (Xiujuan et al., 2010). Estes mostraram que os padrões de parentescos taxonômicos dentro da assembleia de peixes recifais no sul do Brasil parecem uniformes (Clarke & Warwick, 2001; Shan *et al*., 2010), o que já era esperado devido à proximidade entre as ilhas e pela geomorfologia similar dos locais. O índice da VarTD não identificou diferenças na estrutura taxonômica entre as ilhas estudadas, como por exemplo, de uma assembleia formada por alguns gêneros que dão origem a diversas espécies enquanto uma faixa de outros taxas superiores são representados somente por um (ou poucos) taxas (Clarke e Warwick, 2001). Os índices AvTD e VarTD também apresentaram correlação positiva, ou seja, quanto maior a média de distinção taxonômica maior a variação da mesma.

A utilização desses índices pode servir como apoio na escolha de locais preferenciais para conservação, indicando locais que apresentam maiores valores de Distinção Taxonômica Média, os quais se traduzem como dotados de maior resiliência ecológica. Nossos resultados mostraram que a ictiofauna de costão rochoso das ilhas costeiras estudas são: dominadas por poucas espécies; táxons amplamente distribuídos geograficamente; com predomínio de espécies generalistas; e mesmo diferindo na riqueza, densidade e biomassa, as ilhas possuem uma composição taxonômica muito similar.

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Capítulo III

Artigo será submetido a revista ESTUARINE, COASTAL AND SHELF SCIENCE

Otolith fingerprints of the coral reef fish *Stegastes fuscus* in southeast Brazil: a useful tool for population and connectivity studies

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ABSTRACT

Damselfish, *Stegastes fuscus*, is a highly abundant fish species in the Brazilian coasts, being considered a key species for structuring benthic communities on reef habitats. One hundred and twenty adults, ranging from 85 to 120 mm standard length, were collected in April 2013 by spear fishing in six coastal islands located on Cananéia, Paranaguá, Guaratuba and Babitonga bays, southeast Brazil. Elemental and isotopic signatures of whole sagittae were determined by inductively coupled plasma mass spectrometry and isotope ratio mass spectrometry, respectively. Element:calcium (Sr:Ca, Ba:Ca, Mn:Ca and Mg:Ca) and isotopic ratios ($\delta^{18}O$ and $\delta^{13}C$) were analyzed through univariate and multivariate statistics to determine whether these fingerprints can be used to assess the degree of separation between the individuals of these geographic locations. Whole otolith fingerprints representative of the fish entire life-history gave distinct small scale spatial signatures confirming that *S. fuscus* is a sedentary and non-mobile reef species. Classification accuracy rate obtained from quadratic discriminant function analysis of whole otolith chemistry data of adults was relatively high (71% of mean accuracy percentage). Furthermore canonical analysis of principal coordinates from otolith signatures showed the existence of three regional groups probably consequence of similarity of the major estuarine systems in the water environment of the nearby coastal islands where fish were collected. This study suggests that otoliths can be used to study the population structure and connectivity of rocky reef fishes, providing new knowledge to an adequate and rational management of this species.

Key words: Brazilian damselfish, sagittae, fingerprints

INTRODUCTION

The Brazilian damselfish *Stegastes fuscus* (Cuvier, 1830) is an endemic Pomacentridae fish (Floeter & Gasparini, 2000). It is one of the most abundant reefs species in south Brazil (Ferreira *et al*., 2004) and is usually found in shallow coastal waters (Hostim-Silva *et al*., 2006). *S. fuscus* is a non-migratory reef associated fish species (Asoh, 2003) which shows a high territorial feeding behavior (Ferreira *et al*., 2004). It is considered a key species on coastal reefs playing an important role in the benthic communities where they life (Hixon & Brostoff, 1983; Ferreira *et al*.,1998).

S. fuscus is a long-lived and slow-growing fish species, reaching about 15 years of age (Schwamborn & Ferreira, 2002). Individuals are sexually mature with 6.2 and 7.0 cm of standard length for females and males, respectively (Souza *et al*., 2007). The spawning takes place during the dry season mainly from September to February (Canan *et al*., 2011). *S. fuscus* uses the territory for nesting and males protect its eggs from grazers (Thresher, 1991; Canan *et al*., 2011). After hatching, the pelagic larvae have a short growing period of about three weeks (Wellington & Victor, 1989). *S. fucus* is an endangered fish species of the coastal reefs because of the aquatic pollution and over-exploitation for ornamental fish-aquarium trade (Souza *et al*., 2007; Canan *et al*., 2011). To aid in the fishery management there is an urgent need for more information about the *S. fuscus* population structure, connectivity and costal recruitment process.

Otolith chemistry is an innovative approach that can complement the molecular techniques, as a useful tool to elucidate population structure, movement

patterns and connectivity for marine fish that live in an environmental heterogeneous habitat (Bradbury et al., 2008; Smith & Campana, 2010; Correia et al., 2012). Otoliths can be used as natural tags to reconstruct the environmental life history experienced by fishes, since they are metabolically inert structures, mineral material is deposited continuously, and the uptake of elements into the growing structures usually reflects the aquatic environmental proprieties (Campana *et al*., 2000). Otolith fingerprints from fish belonging to different geographic areas can constitute a local distinct elemental signature, temporally stable within each habitat, that can be used to assess the degree of separation between population-units and stocks (Silva *et al*., 2011; Higgins *et al*., 2013; Correia *et al*., 2014). Moreover oxygen and carbon stable isotope ratios have been also used successfully as natural tags for fish population structure studies (Edmonds & Fletcher, 1997; Hidalgo *et al*., 2008; Correia *et al*., 2011). The incorporation of trace elements into otoliths is a complex process, potentially influenced by factors such as salinity, temperature, water chemistry, age and growth, physiology and metabolism, and for most elements (with the exception of Sr and Ba) remains poorly understood (Campana, 1999). However, knowledge of the primary causes behind the incorporation of the metallic species in the aragonitic matrix is facultative for stock discrimination purposes (Thresher, 1999).

The purpose of this work was to investigate the use of the elemental and isotopic composition of otoliths to determine whether *S. fuscus* adult fish captured in six coastal islands in the South Brazil may represent discrete population-units, and if would be differences in otolith chemical signatures at small spatial scales allowing to assess the connectivity among fish groups.

MATERIALS AND METHODS

S. fuscus individuals were sampled by spear fishing in rocky reefs, at a depth above 5 m, in six coastal islands in south Brazil (one in the São Paulo, four in Paraná and one in Santa Catarina states) (Fig. 1). A total of 120 adults (20 per location), ranging from 85 to 120 mm of standard length (average 100 ± 1 mm), were collected in April 2013. In the laboratory, standard length (SL, mm) and weight (M, g) of fish were measured (Table I). Sagittal otoliths were carefully extracted using plastic forceps to avoid metallic contamination and stored dry in plastic vials for further chemical analysis.

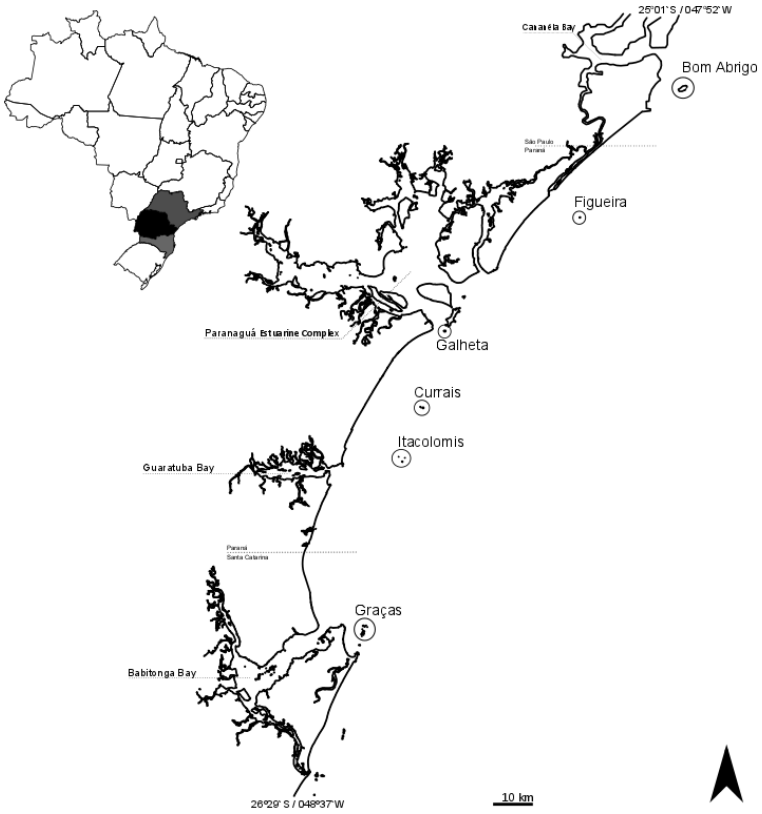

Fig. 1. Map of the south Brazilian coast indicating the six sampling *Stegastes fuscus* locations and the associated estuarine complexes.

Table I. Geographic location, seawater temperatures (SST), sample size (n), standard length (SL) and mass (M) (mean ± SD) of *Stegastes fuscus* used for otolith elemental and isotopic fingerprinting.

Geographic location		n	SST (°C)	SL(mm)	M(g)
Bom Abrigo	25°7.23`S - 048°51.46`W	20	23.95 ± 0.08	100.15 ± 4.34	54.32 ± 9.24
Figueira	25°21.41`S - 048°2.18`W	20	23.67 ± 0.09	94.75 ± 5.79	44.60 ± 9.36
Galheta	25°35.07`S - 048°19.30`W	20	23.57 ± 0.07	105.85 ± 8.80	61.10 ± 11.76
Currais	25°44.12`S - 048°22.02`W	20	23.45 ± 0.11	97.25 ± 4.77	47.37 ± 7.51
Itacolomis	25°50.54`S - 048°24.50`W	20	23.52 ± 0.09	101.05 ± 4.92	61.68 ± 8.89
Graças	26°10.77`S - 048°29.17`W	20	23.37 ± 0.09	100.70 ± 4.73	53.76 ± 7.17

Prior to the chemical analyses, the left sagittae were cleaned in an ultrasonic bath for 5 min in ultrapure water (Milli-Q-Water) followed by immersion in 3% analytical grade hydrogen peroxide (H_2O_2, Fluka TraceSelect) for 15 min to remove the adherent biological tissues. Otoliths were then decontaminated by immersion in 1% nitric acid (HNO_3, Fluka TraceSelect) solution for 10 s followed by a double-immersion in ultrapure water (Milli-Q-Water) for 5 min (Rooker et al., , 2001). Otoliths were stored in new, previously decontaminated, Falcon™ tubes, where they were allowed to air dry in a laminar flow fume hood (Patterson *et al*., 1999). Chemical composition of whole otoliths was determined using solution-based inductively coupled plasma mass spectrometry (SB-ICP-MS). Decontaminated otoliths were weighed on an analytical balance (0.0001 g) and dissolved for 15 min in 10% ultrapure HNO_3 to a final volume of 3 ml (Silva *et al*., 2011). SB-ICP-MS analyses were made using a double focusing magnetic sector field instrument ICP-SF-MS (Thermo ICP-MS x series, Thermo Electron Corporation). This instrument was

equipped with a compact double-focusing magnetic sector mass spectrometer of reversed Nier-Johnson geometry. All measurements were made at a medium resolution setting ($m/\Delta m$ = 4000) to avoid false readings from spectral interferences. The instrument was equipped with a micro flow nebulizer (PFAAR35-1-C1E, Glass Expansion), operated in the self aspirating mode (sample uptake rate ~0.93 L min^{-1}). Quantification of trace elements was based on the external calibration method, preparing multi-element standards that contained the elements of interest in the expected concentration range. To minimize the effect of any plasma fluctuations or different nebulizer aspiration rates between the samples, ^{115}In of a known concentration was added to all samples and standards as an internal standard. Concentrations were calculated by linear interpolation (sum of least squares) based on normalization with the internal standard, and on calibration curves made from single element standards (Merck KGaA) covering the individual expected concentration ranges. A calibration was made at the beginning of each session. The matrix of both the blank and the standard solutions was 1% HNO_3. A preliminary analysis was made to determine the most likely elements (^{44}Ca, ^{88}Sr, ^{137}Ba, ^{26}Mg, ^{55}Mn, ^{7}Li, ^{60}Ni, ^{54}Fe, ^{208}Pb and ^{66}Zn) to serve as environmental indicators, taking into account the metallic species already reported in the otoliths of congener species (*S. nigricans*: Lo-Yat *et al*., 2005; *S. partitus*: Chitarro *et al*., 2006; Chitarro & Hogan, 2013), but excluding elements under strictly physiological regulation (Campana, 2005). Five elements (^{44}Ca, ^{88}Sr, ^{137}Ba, ^{26}Mg and ^{55}Mn) were consistently detectable in whole otoliths and were used for further SB-ICP-MS analysis. Otolith samples were analyzed in random order to avoid possible sequence effects and an otolith certified reference material (FEBS-1) was analyzed for accuracy control quality (Sturgeon *et*

al., 2005). With regard to the analytical accuracy, the elemental concentrations determined in FEBS-1 were within the certified values, with a value of recovery between 78% and 96%. Precision of replicate analyses of individual elements ranged between 1% and 5% relative standard deviation (RSD). The limits of detection were calculated from the individual calibration curves using the three sigma criteria and were (in ppb): ^{44}Ca (30 000), ^{88}Sr (20), ^{137}Ba (5), ^{26}Mg (5) and ^{55}Mn (1).

For carbon and oxygen isotopic otolith analysis (δ^{18}O and δ^{13}C), carbon dioxide (CO_2) was extracted from powdered carbonates (whole right sagittae) in a high vacuum line after reaction with anhydrous orthophosphoric acid for 12 h at 25 °C (Craig, 1957). The released CO_2 was analyzed for carbon and oxygen isotopes in a double inlet, triple collector (SIRA III) mass spectrometer, using BSC (Borborema Skarn Calcite) as the reference gas. BSC was calibrated against NBS-18, NBS-19 and NBS-20. The precision of analysis was better than 0.1‰ based on multiple analyses of the internal standard. The results are expressed in the notation ‰ (per mil) in relation to international VPDB (Vienna Pee-Dee Belemnite) scale (Epstein *et al*., 1953).

Seawater surface temperatures (SST) for each fishing area (4 X 4 km = 16 km^2) were obtained from an open access historical database of the weekly mean sea surface temperatures (http://modis-ocean.gsfc.nasa.gov/) provided by the National Aeronautics and Space Administration (NASA). Lifetime SSTs were calculated for each individual calibrated to the estimated age of fish. Individual annual fish age was obtained using the inverse function of the von Bertalanffy growth curve (VBGC) (Mackay and Moreau 1990) taking into account the parameter estimates of the VBGC for the species (Humann, 1999: L_∞ = 15 cm; Schwamborn & Ferreira, 2002: K =

0.19 y−1 and t0 = −1). Standard length (SL) was previously transformed in fork length (FL) (FL = 0.28 + 1.12 SL) (Schwamborn & Ferreira, 2002).

SB-ICP-MS concentrations of trace elements, originally in μg element L^{-1} solution, were transformed to μg element g^{-1} otolith and then to μg element g^{-1} calcium. Raw data for each element were checked for normality, homoscedasticity and homogeneity of variance-covariance matrices prior to statistical analysis. These assumptions were met after log 10 transformation (log Sr, log Mn and log Mg). Although there were no significant differences in the mean lengths of fish among locations (One-Way ANOVA, n = 120, F = 8.53, $p < 0.05$), we tested for relationships between elemental concentration and fish size (expressed as otolith weight) with analysis of covariance (ANCOVA, otolith weight as co-variate). Otolith elemental concentrations were significantly correlated with otolith mass for all elements, with the exception of Ba (r^2 = 0.02, n = 120, p = 0.098). Sr presented a positive relationship (r^2 = 0.28, n = 120, $p < 0.05$), which was the opposite to Mg (r^2 = 0.06, n = 120, $p < 0.05$) and Mn (r^2= 0.05, n = 120, $p < 0.05$) that showed a very weak negative relationships, although significant. To ensure that differences in fish size among samples did not confound any site-specific differences in otolith chemistry, concentrations of elements were weight-detrended by subtraction of the product of the common within-group linear slope multiplied by the otolith weight from the observed concentration (Campana *et al.*, 2000).

$\delta^{13}C$ and $\delta^{18}O$ values were analyzed by an analysis of covariance (ANCOVA). Otolith weight was considered to be a proxy for age and was used as the covariate in ANCOVA. Location was treated as a fixed factor. $\delta^{18}O$ values were plotted against the individual SSTs averaged over the entire life of the fish. The relationship between

$\delta^{18}O$ values of otolith carbonate and SSTs was explored assuming that the isotopic signature of their carbonate otoliths would de correlated with the water temperature where they resided due to temperature dependent fractionation of $^{18}O/^{16}O$ during the precipitation of the otolith carbonate. It was also assumed that there was no significant variation in the isotopic composition of the ambient seawater across the oceanic areas of interest (Correia *et al*., 2011). Furthermore the potential temporal mismatch between SST and oxygen isotopic signatures due to the fact that most accretion occured in the juvenile phase and proportionally less from older ages, was minimized since fish were from a similar range length and no significant SL differences existed among locations.

One-way analysis of variance (ANOVA) was used to explore individual elemental fingerprint differences between locations. If significant differences were found, this was followed by a Tukey post hoc test. Multivariate analysis of variance (MANOVA) was used to explore multi-elemental fingerprints and detect differences in the multi-elemental otolith composition from different locations. For the MANOVA, we reported the approximate F-ratio statistic for the most robust test of multivariate statistics (Pillai's trace). Post-hoc multivariate pairwise comparisons between locations were performed using the Hotelling T-square test. Multi-element compositions of otoliths were analyzed with a Quadratic Discriminant Function Analysis (QDFA). QDFA was used to visualize spatial differences and to examine the re-classification accuracy success of fishes to this original location. Cross-validations were performed using jackknifed ("leave one out") procedures (Correia *et al*., 2014). The correlation matrix from the elemental and isotopic data set was analyzed by a Canonical Analysis of principal Coordinates (CAP) based on Euclidian distances

(Spearman correlation of 55%) (Anderson and Willis 2003) and the results presented in a two-dimensional biplot (Lo-Yat *et al*., 2005).

The statistical analyses were performed using Systat (version 13.0) and PRIMER 6 + PERMANOVA softwares. The statistical level of significance (α) was 0.05. Data are presented as mean values ± standard errors.

RESULTS

All element:Ca ratios (Sr, Ba, Mg and Mn) and isotopic ratios ($\delta^{18}O$ and $\delta^{13}C$) differed significantly among islands (ANOVA, $p < 0.05$). Galheta island showed the lowest value of Sr:Ca ratio (Tukey test, $p < 0.05$)(Fig. 2A). This island also recorded the lowest value for Ba:Ca ratio although not significantly different from Bom Abrigo, Figueira and Graças (Tukey tests, $p > 0.05$) (Fig. 2B). Galheta also exhibited the highest value of Mg:Ca ratio comparatively to the other islands, with exception of Itacolomis (Tukey tests, $p < 0.05$) (Fig. 2C). Figueira presented the lowest value of Mn:Ca ratio comparatively to the other islands with exception of Currais (Tukey tests, $p < 0.05$) (Fig. 2D). The mean otolith isotopic ratios obtained from the six sampling locations ranged from -8.81‰ to -8.07‰ and from -1.64‰ to -0.33‰ for $\delta^{13}C$ and $\delta^{18}O$, respectively. For $\delta^{18}O$ Bom Abrigo, Galheta and Graças islands showed the lowest mean values (Tukey tests, $p < 0.05$) (Fig. 2E). Itacolomis showed the highest value for $\delta^{13}C$, but not significantly different from Figueira (Tukey tests, $p < 0.05$) (Fig. 2F).

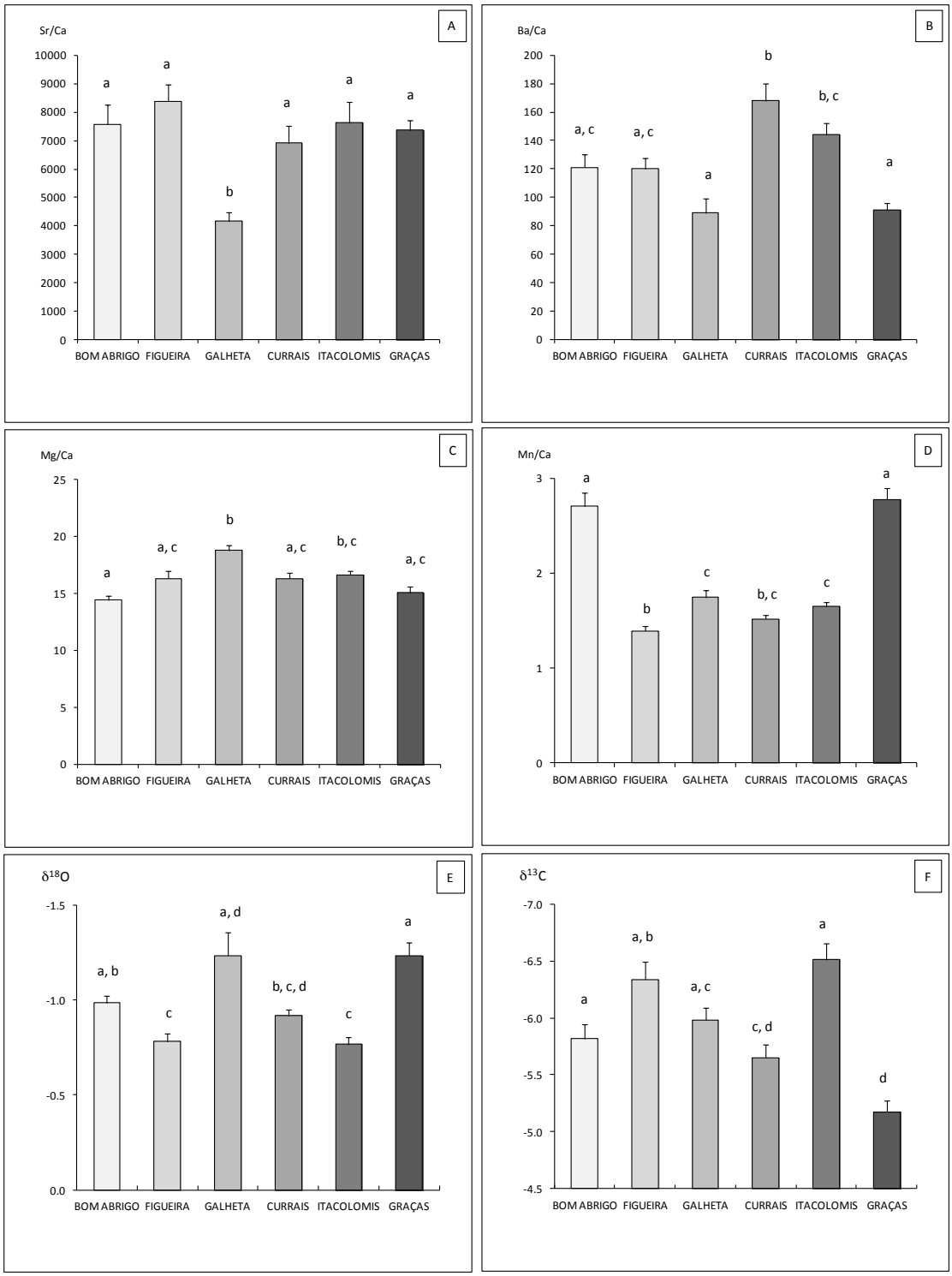

Fig. 2. Elemental and isotopic concentrations (mean ± SD) observed in the whole otoliths of *Stegastes fuscus* from fishes collected in South Brazil. Elemental and isotopic concentrations are given in µg element g^{-1} calcium and VPDB (‰), respectively. The locations marked with the same letter above the error bars are not significantly different from each other ($P > 0.05$).

$\delta^{13}C$ showed no significant relationships with otolith mass (Fig. 3A) and 35% of the sum of squares was explained by location (Table II). For $\delta^{18}O$, 44% of the sum of squares was explained by location and although otolith mass was significant, it only explained less than 1% of the sum of squares (Fig. 3B) (Table II). No relationship was found between otolith $\delta^{18}O$ signatures and the individual averaged SSTs experienced by fish (Fig. 4). The bi-plot using the both isotopes ratios suggests that the isotopic signatures overlap for all locations, with exception of Graças in which individuals appeared to have a more site specific signal (Fig. 5).

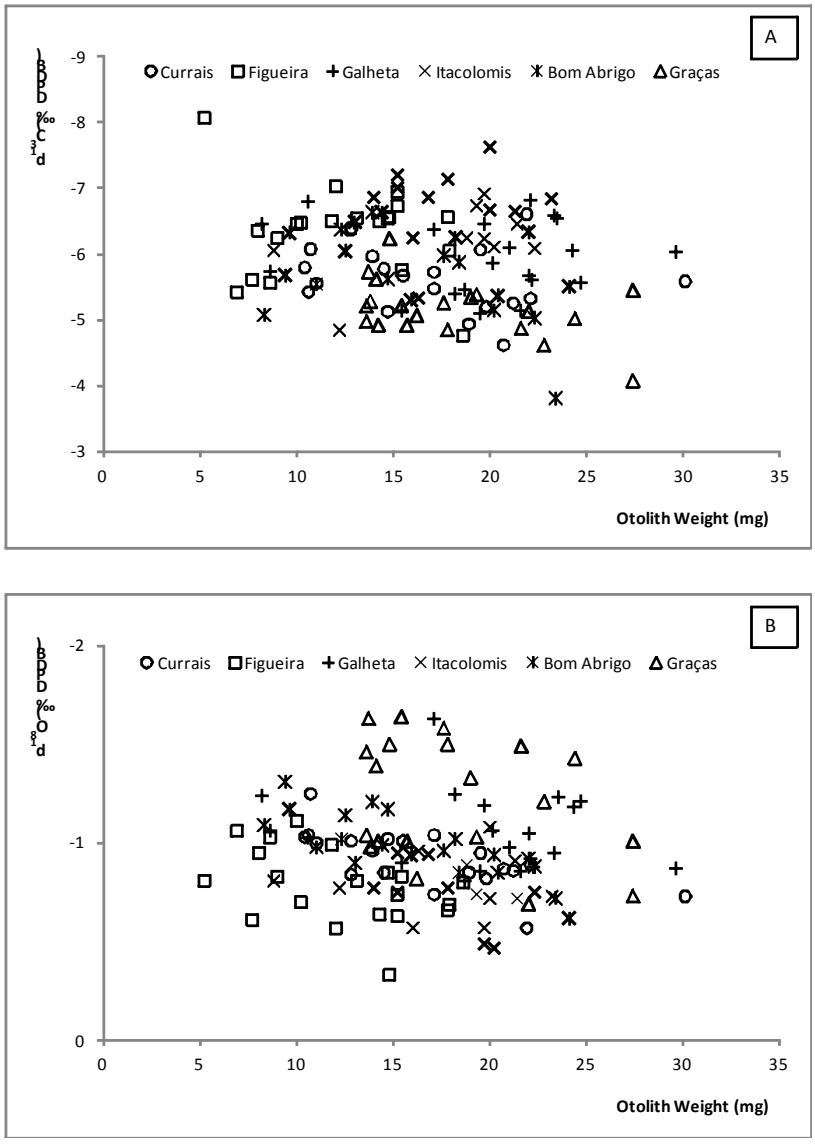

Fig. 3. $\delta^{13}C$ (A) and $\delta^{18}O$ (B) versus otoliths mass for all data.

Table II ANCOVA for $\delta^{13}C$ and for $\delta^{18}O$ values of otolith carbonate

	Source	DF	SS	MS	F-RATIO	P-VALUE
$\delta^{13}C$						
	Location	5	22.056	4.411	12.647	0.000
	Otolith Weight	1	1.322	1.322	3.789	0.054
	Error	113	39.414	0.349		
	Total	119	62.792			
$\delta^{18}O$						
	Location	5	3.629	0.726	20.968	0.000
	Otolith Weight	1	0.733	0.733	21.171	0.000
	Error	113	3.911	0.035		
	Total	119	8.273			

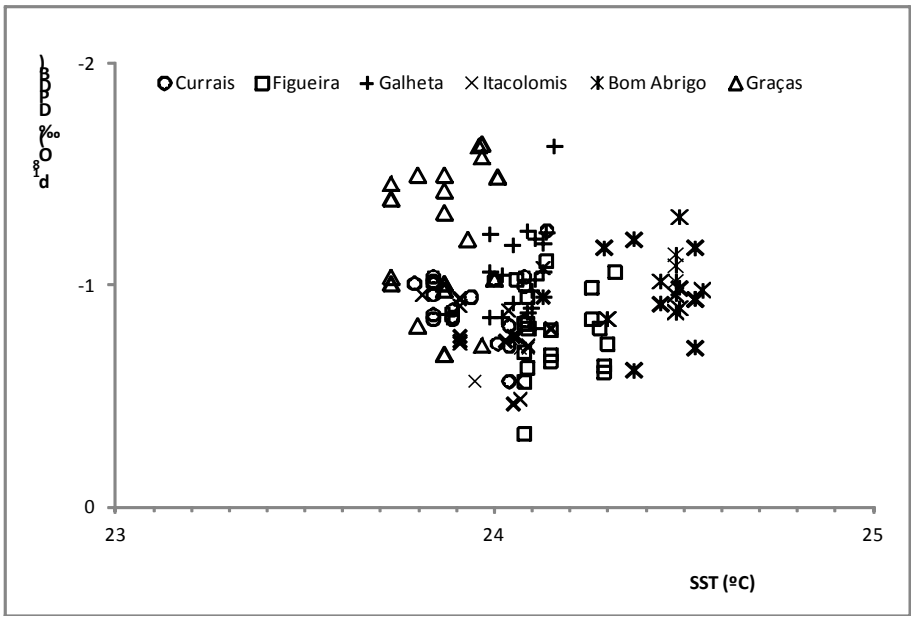

Fig. 4. $\delta^{18}O$ versus SST for all *Stegastes fuscus* individuals.

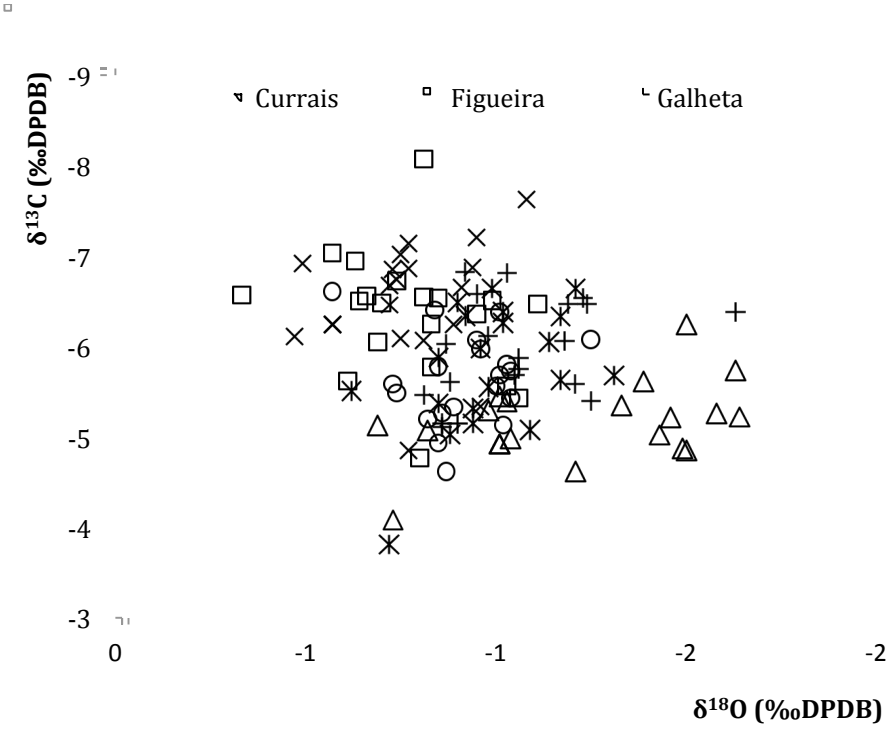

Fig. 5. $\delta^{13}C$ versus $\delta^{18}O$ for sagittal otolith carbonate from *Stegastes fuscus*.

MANOVA indicated a significant difference in the multi-elemental signatures of the whole otoliths (Pillai Trace, $F_{30,565} = 11.059$, $p < 0.05$). All pairwise comparisons gave significant differences between locations, with exception of Figueira and Itacolomis (Hotelling's T-Square Trace, $F = 13.428$, $p = 0.103$). Both islands did not show any univariate pairwise differences, with exception of the Mn:Ca ratio (Tukey tests, $p < 0.05$). For each pair of groups, Figueira and Itacolomis ($F_{6,109} = 2.140$) and Figueira and Graças ($F_{6.109} = 58.035$), showed the lowest and highest Mahalanobis distances (Between Group F- Matrix), respectively.

QDFA plot showed a separation among the coastal islands based on the elemental and isotopic composition of otoliths, although some overlap was evident for some regions namely for Figueira, Currais and Itacolomis (Fig. 6). Jackknifed

classification accuracy was moderate to high ranging from 55% (Itacolomis) to 80% (Bom Abrigo and Currais), and showed an overall mean of 71% (Table III).

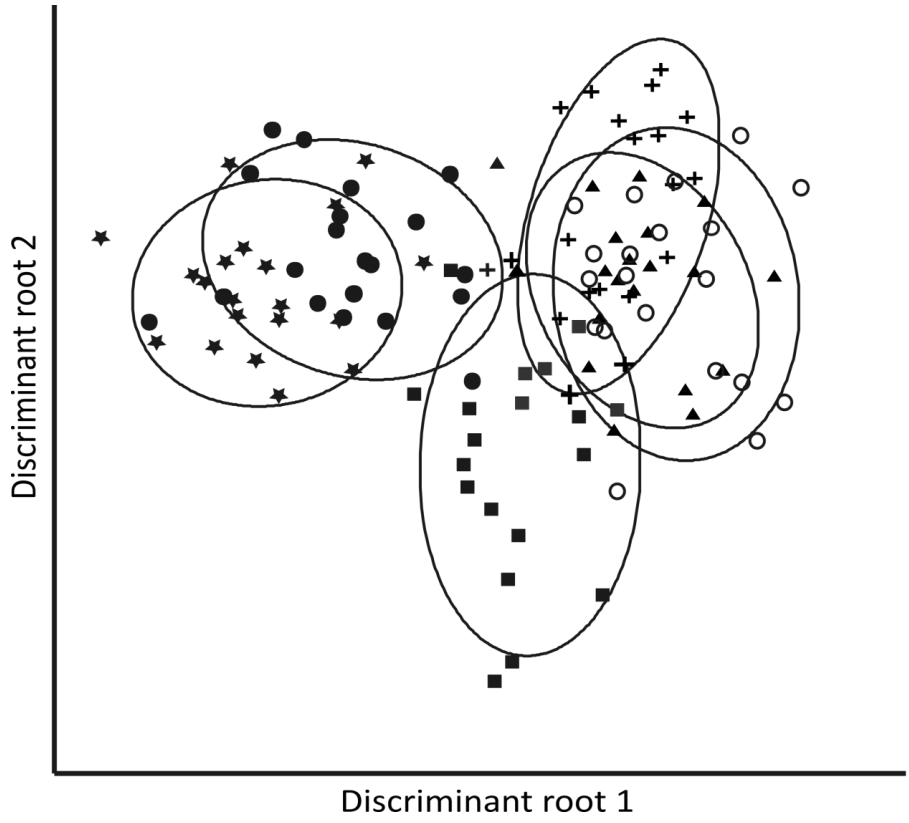

Fig. 6. Canonical variate plots displaying spatial differences in multi-elemental tags of *Stegas fuscus* whole otoliths from South Brazil. Bom Abrigo Island (▯), Figueira Island (o), Galheta Island (n), Currais Arch. (□), Itacolomis Island (⏏) and Graças Arch. (□). Ellipses represent 95% confidence intervals around the data and symbols represent individual fish.

Table III. Jackknife classification matrix of *S. fuscus* adults based on whole otolith's used in quadratic discriminant function analysis.

	Predicted Location						
Real Location	Bom Abrigo	Figueira	Galheta	Currais	Itacolomis	Graças	**%Correct**
Bom Abrigo	16	0	2	0	0	2	80
Figueira	0	11	1	3	5	0	55
Galheta	0	1	15	2	2	0	75
Currais	0	2	1	16	1	0	80
Itacolomis	1	6	0	1	12	0	60
Graças	5	0	0	0	0	15	75
Total	22	20	19	22	20	17	**71**

The CAP identified three main groups in two-dimensional space composed by individuals from Galheta (Group 1), Bom Abrigo and Graças (Group 2), and Currais Figueira and Itacolomis (Group 3). The vectors for Mn:Ca and $\delta^{13}C$ were aligned with the group 2 , and Ba:Ca and $\delta^{18}O$ vectors with group 3 (Fig. 7).

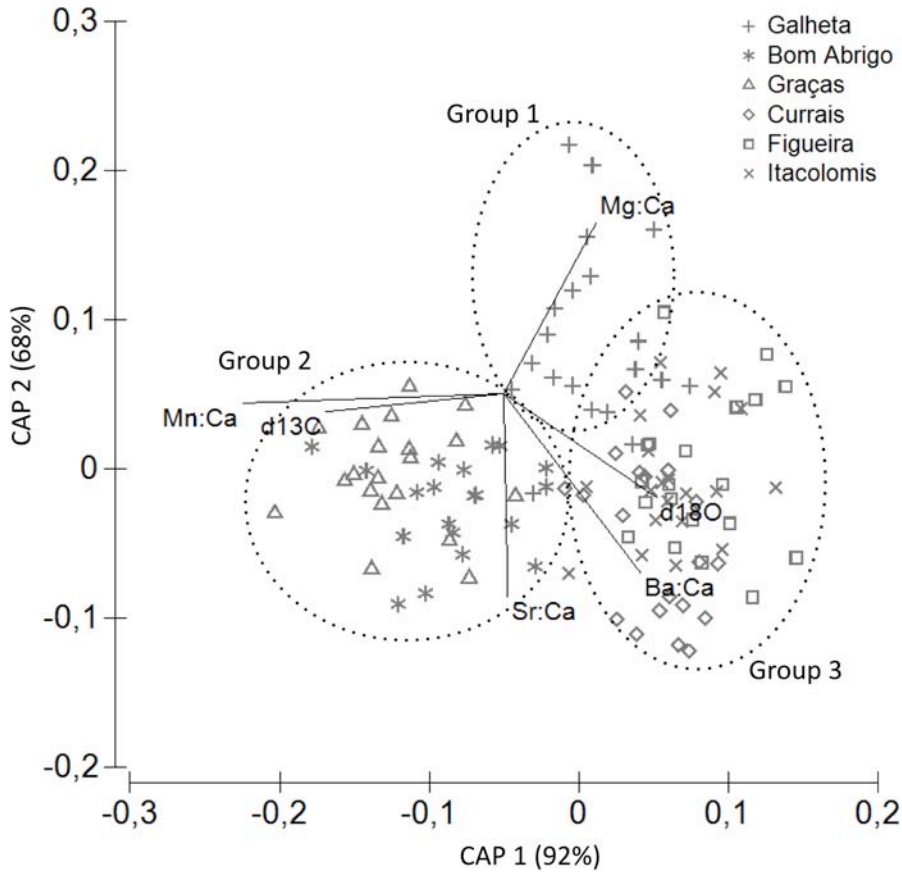

Fig. 7. Canonical analysis of principal coordinates (CAP) plot of the elemental and isotopic otolith signatures from *Stegastes fuscus* (n = 120) collected in the southeast coast of Brazil. Ellipses are 95% confidence limits for the three groups defined by the CAP.

DISCUSSION

Elemental fingerprinting is a useful tool in determining the structure and connectivity among fish population-units at spatial (Silva *et al*., 2011; Higgins *et al*., 2013; Huijbers *et al*., 2013) and temporal scales (Hamer *et al*., 2003; Cook 2011; Correia *et al*., 2014). The incorporation of trace elements into otoliths is a complex process poorly understood but mainly influenced by abiotic (salinity, temperature, water chemistry) and biotic (age, growth, physiology and diet) factors (Webb et al.,

2012; Woodcock et al., 2012; Barnes & Gillanders, 2013). The incorporation of Ba and Sr into otoliths is known to be influenced by salinity ambient concentrations (Elsdon & Gillanders, 2003; Martin & Wuenschel, 2006; Walther & Thorrold, 2006), although temperature and growth rate may also affect the incorporation of the former metallic species in otoliths (Townsend et al., 1992; Sadovy & Severin, 1994; Elsdon & Gillanders, 2004). For Mn and Mg there is no clear relationship between their concentration in otoliths and in surrounding water, and variation appears to be related to unclear endo and exogenous process (Martin & Wuenschel, 2006; Hamer & Jenkins, 2007; Woodcock *et al*., 2012). Moreover several studies have shown that stable oxygen ratios ($\delta^{18}O$) in otoliths can be used as a proxy of the ambient sea temperature (Radtke et al., 1996; Thorrold et al., 1997; Høie et al., 2004), while carbon isotope ratios ($\delta^{13}C$) are mainly influenced by fish metabolism and feeding regime (Kalish, 1991; Schwarcz et al., 1998; Høie et al., 2003), and by the dissolved inorganic carbon in the water (Thorrold et al., 1997; Patterson, 1999; Solomon et al., 2006).

Elemental or isotopic fingerprints of whole otoliths provide an environmental natural tag integrated over the fish's entire life, i.e. from birth until dead (Campana, 2000). Non-migratory and highly territorial fish species, such as *S. fuscus* (Alosh, 2003) may preserve unique chemical signatures corresponding of the site where they lived (Kingsford & Gillanders, 2000; Lo-Yat et al., 2005). The chemical composition of the whole otoliths of *S. fuscus* adults was based on trace elements commonly used in previous studies, including Pomacentridae fish belonging to the same genus (Lo-Yat *et al.,* 2005; Chittaro *et al*., 2006; Chittaro & Hogan, 2013). The hereby obtained concentrations are within the reported values for other marine

species (Albuquerque *et al*., 2012; Higgins *et al*., 2013; Correia *et al*., 2014).

The spatial and temporal variation of the otolith's chemical signal for other *Stegastes* spp. has been already addressed by other studies (Lo-Yat *et al*., 2005; Chittaro et al., 2006; Chittaro & Hogan, 2013). In the present study, the small scale chemical composition variation of otoliths of *S. fuscus* was assessed in a geographic area ranging from ten to hundreds kilometers. Similarly, patterns of connectivity among populations of *S. partitus* in the west Caribbean Sea were assessed using chemical signatures recorded in the otolith's edge, both at small and large regional scales, suggesting a substantial self-recruitment in some areas (Chittaro & Hogan, 2013). Furthermore, whole chemical otolith analysis in *S. nigricans* from the French Polynesia showed significant differences among nearby reefs (distances less than 200 meters) suggesting the effectiveness of this tool to study the connectivity among populations at small scale distances (Lo-Yat *et al*., 2005).

In the present study all individuals were captured in shallow coastal waters (less than 4 meters) and therefore no variation was expected to occurs due to the collection water depth (Kingsford & Gillanders, 2000). However, variation in water chemistry would be expected to occur in coastal environments due to the presence of estuaries, human activities, pollution and freshwater runoff regimes (Kingsford & Gillanders, 2000; Forrester & Swearer, 2002; Hamer et al., 2003). The hereby sampling area represents a distance of 140 km between the most distant islands (i.e., from Bom Abrigo to Graças). This area is under the direct influence of four major estuaries located in the southeast Brazilian coast (Diegues & Rosman, 1998). This climate region is under the influence of the subtropical type characterized by

well-distributed rains through the year and a drier winter (Peel et al., 2007), with mean annual rainfall and temperature of 2500 mm and 22°C, respectively (IPARDES, 1989). The principal estuary, Paranaguá Estuarine Complex, has approximately 550 km^2 of flooded surface area (Noernberg *et al*., 2006). Cananéia and Babitonga bays have about 150 km^2 flooded surface area (Miyao *et al*., 1986; IBAMA, 1998) while Guaratuba , the smallest estuary, has only 50 km^2 flooded surface area (Mizerkowski *et al*., 2012). Human activity is greater in Paranaguá and Babitonga Bays comparatively to Guaratuba and Cananéia Bays, mainly because of the shelter industries, ports and the existence of a high population density (IPARDES, 1989; IBAMA, 1998; Romero *et al*., 2010).

Three groups were somewhat distinguished by the visual inspection of the QDFA and CAP plots: the Galheta island is the nearest of the coast, being located in the outfall of the Paranaguá Estuarine Complex (PEC); Bom Abrigo and Graças, located about 6.5 km of the Cananéia and Babitonga bays respectively; and Figueira, Currais and Itacolomis islands, located approximately 9 km of coast, with a distance ranging between 13 and 33 km from the nearest bay. Individuals collected in Galheta Island, near the mouth of PEC, presented in their otoliths low levels of Sr and Ba, and high levels of Mg. The low Sr concentration could be related with the output of the estuarine freshwater, since it is well known the positive relationship between Sr and water salinity (Webb *et al*., 2012). However, it is difficult to identify the cause behind the high content of Mg in Galheta individuals. Although it was been recently found a positive relationship among Mg:Ca ratios in otoliths and water temperature (Barnes & Gillanders, 2013), the reported SSTs of the sampling locations, at least considering the mean of the last ten years, are relatively similar (~23°C). It means that this

difference is probably related with other abiotic or physiological processes (Woodcock *et al*., 2012). Located in the internal coastal shelf of the Paraná, Figueira, Currais and Itacolomis islands, did not suffer the influence of the estuarine plumes, and the coastal waters are mixed by winds and currents (Brandini et al., 2007; Nemes & Maroni, 2013).

Considering that the observed averaged water temperature range within the study area is only of about 1 degree C, as reported by a previous study (Brandini et al., 2007), this would correspond to about only 0.2 per mil difference in the oxygen isotopic ratio (Hoie et al., 2004). This suggests that the small $\delta^{18}O$ differences founded in individuals from different islands are probably related with the environmental salinity (Elsdon & Gillanders, 2002). In Bom Abrigo, Galheta and Graças islands the mean values of $\delta^{18}O$ were significantly lower than the other locations. These islands are located in proximity of an estuary, where the salinity is low due to freshwater runoff. The input of freshwater from estuaries, was likely an important factor in explaining the relatively low otoliths $\delta^{18}O$ values (Correia *et al*., 2011). However otolith $\delta^{18}O$ values directly reflect water $\delta^{18}O$ values, as modified by temperature (Høie *et al*., 2003), which are unavailable for the sampling area. For $\delta^{13}C$ the results did not shown any general trend, being difficult to suggest factors which could have influenced the present data. It is well known that $\delta^{13}C$ values measured in fish otoliths can be influenced by ontogenetic changes in trophic levels that comprise the fish diet and metabolism (Schwarcz *et al*., 1998; Gao & Beamish, 2003; Gao *et al*., 2004), but may also reflect geographic variation in the $\delta^{13}C$ of the DIC of the ambient water (Thorrold *et al*., 1997; Patterson, 1999; Solomon *et al*., 2006).

The present study was not designed to determine the factors responsible for the incorporation of the trace elements and stable isotopes ratios into otoliths. But, as already mentioned, this is not a prerequisite for the use of otolith chemical signatures as fish natural tags (Thorrold *et al*., 1998). However the hereby data suggests, for the first time, that unique chemical signatures within otoliths of *S. fuscus* can occur at local scales in some coastal environments in South Brazil. Since *S. fuscus* appear to be a site-attached and non-mobile fish and given that the only opportunity for dispersal is during the three week larval period, both traits may prove useful for future fish connectivity studies within reef scales. By comparing the larval core (natal) signatures of individuals of the same cohort using laser-based analysis it would be possible to assess the contribution of each island, as spawning or nursery area, to the overall adult population. Answering this relevant ecological question is essential for the effective management of the species.

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Capítulo IV

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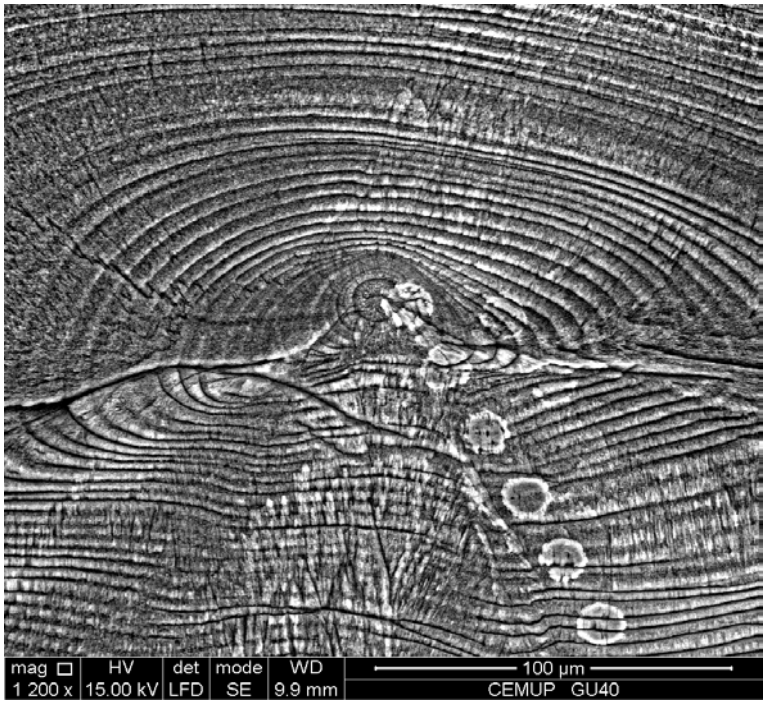

Habitat residency and movement patterns of *Centropomus parallelus* juveniles in a Brazilian subtropical estuarine complex determined by otolith microchemistry (Sr:Ca ratios) and microstructure (primary increments) analyses.

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ABSTRACT

Fat snook *Centropomus parallelus* is a important amphidromous species of the tropical and subtropical western Atlantic comercially valuable in terms of fisheries and aquaculture. At present populations of *C. parallelus* are threatened by aquatic pollution, habitat loss and overfishing. Sixty *C. parallelus* juveniles were collected in March 2013 in two locations (Tromomó and Guaraguaçu) inside the Paranaguá Estuarine Complex, southern Brazil. The habitat residency and movement patterns of the individuals were inferred from the Sr:Ca ratios and the age recorded in the otoliths. Data suggest that the species spawns preferentially in brackish areas mainly from October to January, and that growth rate during the early juvenile stage could be influence by environmental salinity. Furthermore, the data also shows that *C. parallelus* could occupy diverse salinity habitats and migrate among marine, brackish and freshwater areas within the Paranaguá Estuarine Complex showing a high environmental plasticity and adaptation. This new ecological information is essential for a rational fisheries management of the species.

Key-words: Centropomidae, sagitta, microstructure, microchemistry, life-cycle.

INTRODUCTION

The fat snook *Centropomus parallelus* is an important eurihaline species for recreational and commercial fisheries (Mendonça & Katsuragawa, 2001) and has a large aquaculture potential (Corrêa & Cerqueira, 2009), since it is a valuable food source (Alvarez-Lajonchère & Tsuzuki, 2008). It is a fish species that inhabits inshore waters, estuaries and coastal lagoons of the tropical and subtropical western Atlantic, occurring from Florida to the southern coast Brazil (Rivas, 1986). In the Paranaguá Estuarine Complex (PEC), *C. parallelus* is found in several environments, ranging from marine coastal to freshwater streams habitats (Spach *et al.,* 2004; Felix *et al*., 2007; Contente *et al*., 2011; Vitule *et al.*, 2013).

C. parallelus is considered an amphidromous fish, i.e. it migrates between freshwater and saltwater during a portion of its lifecycle (Riede, 2004; Silvano *et al*., 2006). It has a feeding regime mainly based on fish, insects and crustaceans, although early juveniles are also zooplanktivorous (Corrêa & Uieda, 2007; Alvarez-Lajonchère & Tsuzuki, 2008; Feltrin-Contente *et al*., 2009). *C. parallelus* is a protandric hermaphrodite species which means that individuals become sexually mature first as males and later undergo a sex conversion to female as they grow (Alvarez-Lajonchère & Tsuzuki, 2008). It spawns asynchronously near river mouths, inlets, bays, estuaries, islands, or in coastal inshore waters (Silvano *et al*., 2006; Alvarez-Lajonchère & Tsuzuki, 2008). The pelagic eggs and larvae drift into brackish water swamps or mangroves to develop (Alvarez-Lajonchère & Tsuzuki, 2008). Embryonic development last approximately 20 h after fertilization (Cerqueira & Tsuzuki, 2009) and post-larval settlement occurs about $2^{1/2}$ weeks after hatching (Itagaki, 2005). The complete transformation to the juvenile stage occurs at age of

40 days with early juveniles showing a total length of 10 mm (Alvarez-Lajonchère *et al*., 2002). For the Brazilian coast, *C. parallelus* did not show evidence of genetic spatial differentiation, suggesting the existence of high gene flow (Prodocimo *et al*., 2008).

At present *C. parallelus* populations are considered threatened by overfishing, water pollution and habitat loss (Rocha *et al*., 2007; Feltrin-Contente *et al*., 2009). Governmental fisheries regulations (resolution nº 016/2009) are currently imposed in the Paraná State such as minimum and maximum landing sizes (40 and 50 cm, respectively) and closing of fishing season from November to December (SEMA 2009).

Estuaries, besides providing habitats for many fishes, work frequently as nurseries areas for growing of larvae and early juveniles before recruiting to adult populations (Able, 2005). Estuaries are also characterized by temporal and spatial fluctuations of abiotic factors, namely temperature and salinity, mainly due to the freshwater runoff inflow and tidal cycles, creating a very dynamic physicochemical environment (Heupel & Simpendorfer, 2008; Tyler et al., 2009). It is well known the relationship between the spatial distribution of estuarine fish and such abiotic factors (Marshall & Elliott, 1998), being salinity one of primary factors influencing the habitat use and movement of fish within an estuary (Harrison & Whitfield, 2006; Selleslagh & Amara, 2008; Passos *et al*., 2013).

Fish movements have been studied using a variety of tools, such as mark and recapture, telemetry and otolith chemistry (Campana *et al*., 1999; Trotter *et al*., 2012; Liu *et al*., 2014). Otoliths are metabolically inert structures, newly mineral material is neither resorbed nor reworked after deposition, and the uptake of

elements into the growing structures usually reflects the physical and chemical aquatic environment (Campana *et al*., 2000). The Sr:Ca ratios of otoliths can be used as natural tags to describe the fish movements between freshwater, brackish and seawater habitats (Secor & Rooker, 2000; Suzuki *et al*., 2011; Mai *et al*., 2014). Furthermore, for a wide range of salinities and fish species a well-known positive relationship exists between Sr:Ca ratios in the otoliths and the water where fish lived (Kraus & Secor, 2004). Using Sr:Ca ratios linked to the chronological proprieties of otoliths, the individual movement of a fish can be retrospectively tagged in a given population (Elsdon & Gillanders, 2006).

The objective of this study was to examine the habitat residency and movement pattern of juveniles *C. parallelus*, an estuarine-dependent species in PEC, obtained from Sr:Ca ratios and microstructural analyses of otoliths.

MATERIAL AND METHODS

STUDY AREA

The Paranaguá Estuarine Complex (PEC) (Fig. 1) has an area of 612 km^2 and is characterized by a diversity of habitats, like tidal flats, channels, mangroves, tidal creeks, estuarine beaches, rivers and rock shores (Lana *et al*., 2001). It is a partially mixed estuary with semidiurnal tides and diurnal inequality, which is connected to the Atlantic Ocean, in the east, by Sueste and Galheta Channels (Knoppers *et al*., 1987). The PEC is divided in five sectors and in twelve sub-estuaries based on the morphological and hydrological characteristics The Guaraguaçu river is characterized by a large mesohaline coastal plain drainage area, about 397 km^2, that runoffs to the Cotinga Sub-estuary, Mixture Sector. The Tromomó site, a polyhaline area, is located

in the mouth of Serra Negra River that belongs to the Benito sub-estuary, Laranjeiras Sector, being the biggest drainage area of the PEC (Noernberg *et al*., 2006).

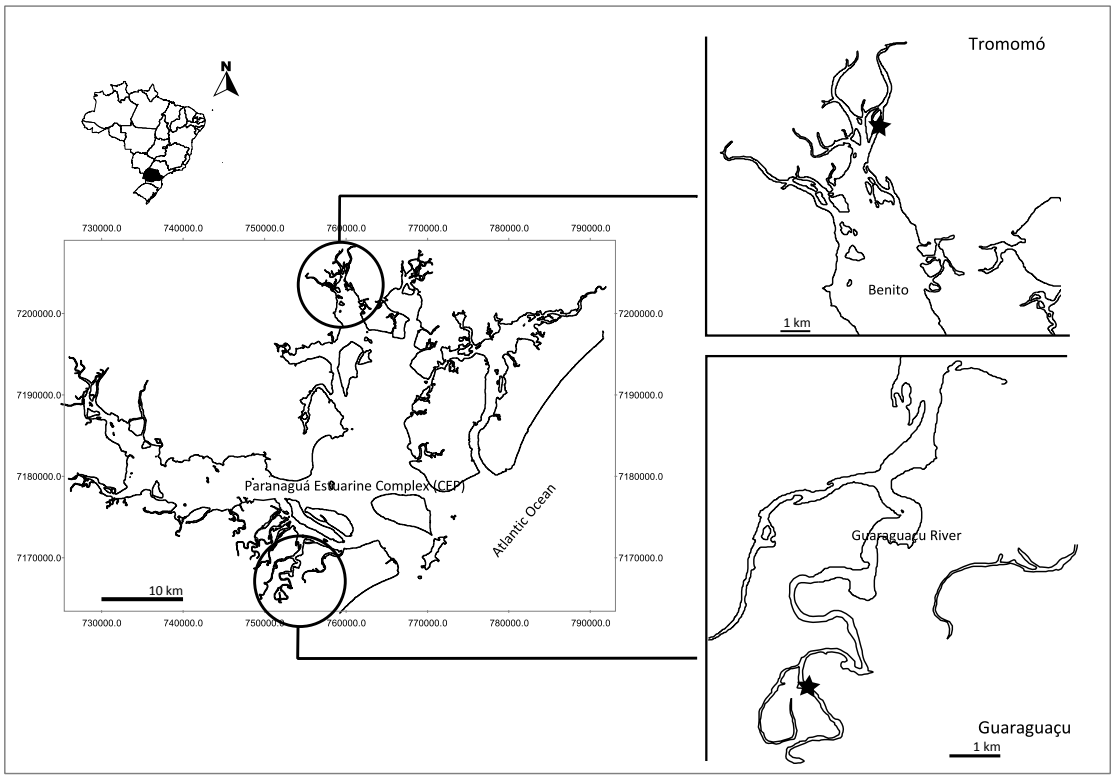

Fig. 1. Location of the Paraná state in the Brazil map (inset). *Centropomus parallelus* sampling sites within the Paranaguá Estuarine Complex (PEC) indicating the sampling locations (*).

BIOLOGICAL SAMPLING

Sixty fat snook early juveniles were sampled in March of 2013. Fish collection took place using a seine net (15 m long with a stretched mesh size of 5 mm) operated from the margin by two people, within the PEC in two different sites (Tromomo and Guaruaçu, a polyhaline and mesohaline site, respectively). In laboratory the fishes were measured (SL, mm) and weighted (W, g). Sagittal otoliths

were extracted from the otic cavity, rinsed with freshwater, air dried and stored in Eppendorf vials until further analysis.

OTOLITH PREPARATION

The left sagittal otoliths were cleaned of organic tissues using distilled water, air-dried and mounted in epoxy resin (Struers, Epofix) with the sulcus acusticus down. The blocks were sectioned near the otolith margins by cutting away the excess resin with a low speed diamond saw (Buehler, IsoMet) at 6000 rpm. Otoliths were ground in the transverse plane to expose the core with 800, 1200 and 2400 silicon carbide papers (Hermes), making regular optical inspections under a metallographic microscope (Meiji, ML7100), and further polished with 6, 3, 1 and 1/4 µm diamond pastes (Buehler, Metadi II). Finally, otoliths were cleaned in an ultrasonic bath with ultrapure water (Milli-Q water) and given a carbon coating by high vacuum evaporation. Sr and Ca concentrations (% dry weight) were measured along the ventral ridge of the sulcus from the core to the edge using an X-Ray Electron Probe Micro-Analyzer (EPMA, JEOL JXA-8500F). Apatite [$Ca_5(PO_4)^3$] and celestite ($SrSO_4$) were used as standards. Accelerating voltage and beam current were 15 kV and 20 nA, respectively. The electron beam was focused on a point about 10 µm in diameter, spacing measurements at 20 µm intervals. The acquisition time was 180 s (30 s per element, 30 s for the measurement of the counts in the corresponding peak and 30 s for measuring background contribution) per point. Limit of detection were 100 ppm. The microprobe measurement points, which were seen as burn depressions on the otolith surface, were assigned latter to otolith growth increments. The averages of successive data for Sr and Ca concentrations

pooled for every ten successive growth increments were used for the life history transect analysis. The results are presented as the amount of Sr divided by the amount of Ca times 1000. Following microprobe analysis, the otolith surface was repolished with diamond pastes (1/4 µm), etched for 2 minutes with 5% EDTA, cleaned in an ultrasonic bath with ultrapure water (Milli-Q water) and vacuum coated with Au/Pd for scanning electron microscope observation (Quanta 400 FEG ESEM / EDAX genesis X4M) at 15 kV and 700 X magnification. The primary increment measurements were performed using ImageJ in combination with the ObjectJ plugin.

The averages of every five successive micro-increments from the core to the otolith edge were used for otolith growth analysis. Primary increments were assumed to be deposited daily for this species (Itagaki, 2005) (Fig. 2). Although a data review literature indicates that the mean Sr:Ca ratios of the teleosts fish are highly variable, it is noteworthy that the values of Sr:Ca X 1,000 for perciformes are significantly different between certain concentric zones in otoliths, reflecting the freshwater (2.8 ± 1.3), brackish water (6.2 ± 1.0) and seawater (8.4 ± 2.9) habitats (Yang *et al*., 2011). Furthermore Sr:Ca ratios recorded in the otolith edge of Guaraguaçu (mesohialine environment) and Tromomó (polyhialine environment) individuals were from 4.8 to 9.3 and 8.0 to 11.4, respectively. According to this information and assuming similar approaches (Tabouret *et al*., 2010), the reconstruction of the history of *C. parallelus* habitat-use was made considering for all individuals, irrespective of sampling location, that Sr:Ca ratios ($x10^3$) between 2-5, 5-8 and 8-11 were considered as fresh, brackish and seawater residency, respectively. Furthermore, it was also assumed that otoliths in the present study do not present

vateritic inclusions since no dark areas were observed under reflected light after EDTA etching (Tzeng *et al*., 2007).

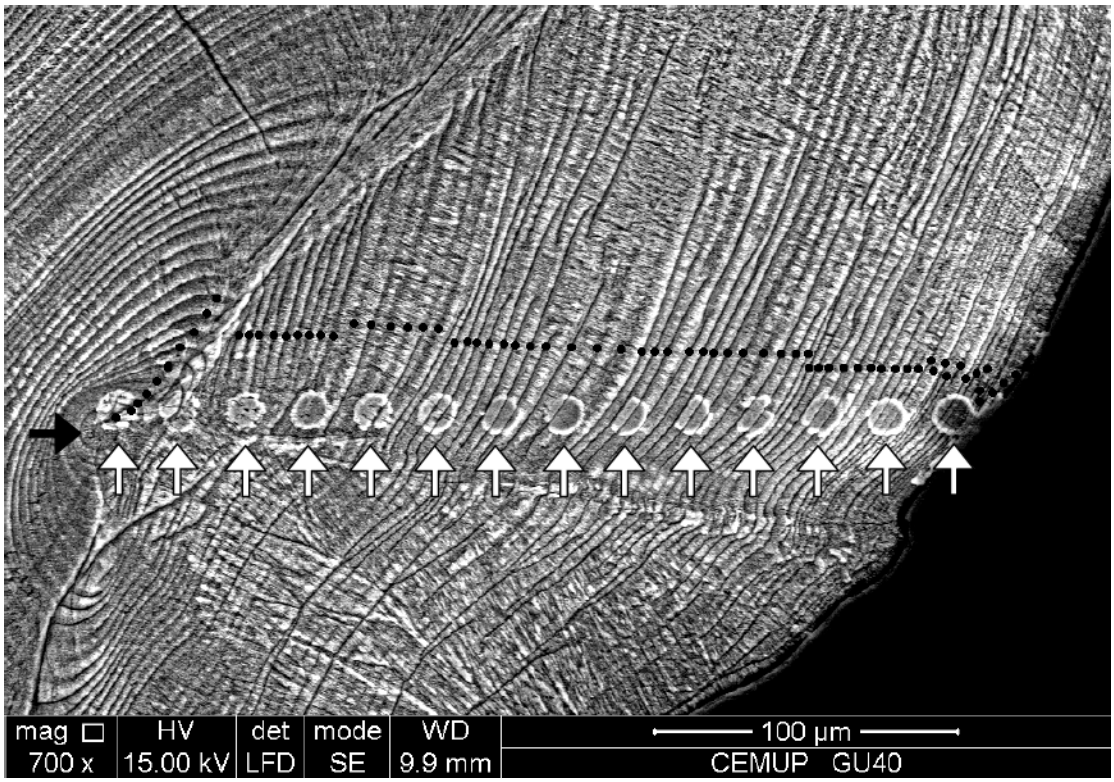

Fig. 2. Transverse section from the sagittal otolith of a 72 days-old *C. parallelus* individual (SL = 24 mm) collected in Guaraguaçu showing the primary increments (black dots) and the location of the burn depressions (white arrows), made by the electron microprobe, from the core (black arrow) until the edge.

STATISTICAL ANALYSIS

The statistical analyses were performed using R (version 2.15.3). Sr:Ca ratios ($x10^3$) concentrations differences for cores and edges between the individuals of the two samples points were assessed using Student t-tests. The statistical level of significance (α) was 0.05. Data are presented as mean values ± standard deviation.

RESULTS

The overall of the juveniles of *C. parallelus* showed a SL ranging from 21 to 55 mm. The post-hatching ages were comprised between 61 and 157 days. SL and age showed no significant differences between the locations (t = -0.348, d.f. = 56.32, P = 0.729 and t = 1.367, d.f. = 35.99, P = 0.18, respectively). Reproduction dates back-calculated from estimated otolith daily ages, indicated that the *C. parallelus* has multiples spawns per year, with a peak occurring between October and January.

Strontium:Ca ratios ($x10^3$) ranged from 2.3 to 11.2 and from 5.8 in to 13.3 in Guaraguaçu and Tromomó, respectively. The *C. parallelus* caught in both locations showed no significant differences in otolith's cores for the Sr:Ca ratios concentrations (t = 0.116, d.f. = 57.77, P = 0.908) showing an overall value of 7.8 ± 1.5 . For de otolith edges Sr:Ca ratios were statistically differents (t = -13.114, d.f. = 55.96, P <0.001) among the Guaraguaçu (6.3 ± 1.0) and Tromomó (9.5 ± 0.9) (Table I).

Table I. Collection site, geographic coordinates, date, sample size (N), standard length (SL), age and Sr:Ca ratios of *Centropomus parallelus*.

Sites	**Location**	**Date**	**N**	**SL** (mm)	**Age** (post-hacthing days)	**Sr:Ca** ($x10^3$) (Mass %) Mean ± sd
Guaraguaçu	25°36.151` S 48°29.465` W	30/03/2013	30	Max = 55 Min = 23 Mean ± sd = 37±10	Max = 149 Min = 70 Mean ± sd = 109 ± 27	Core: 7.8 ± 1.5 Edge: 6.3 ± 1.0
Tromomó	25°15.845` S 48°24.641` W	21/03/2013	30	Max = 53 Min = 21 Mean ± sd = 37±9	Max = 157 Min = 61 Mean ± sd = 116 ± 25	Core: 7.8 ± 1.6 Edge: 9.5 ± 0.9

High resolution life-history scans of Sr:Ca ratios in the otoliths from core to edge allowed several types of residency patterns to be distinguished. Six patterns of fish movement were record in the *C. parallelus* individuals caught in PEC (Fig. 3). The

observed number of patterns depends however on how fine a detail one puts on them, but observed Sr:Ca ratios profiles where grouped to minimize the existent number of profile patterns without losing relevant information. Some patterns may however exist in the same catchment site.

The first profile (Fig. 3 - Type 1) was observed for 33% of the individuals caught in PEC (but represented 66% of the individuals caught at Tromomó). These individuals showed consistently medium values of Sr:Ca ratios in the core increasing until 30-40 days post-hatching (brackish water), followed by high and constant Sr:Ca ratios throughout their remaining life history (saltwater) (marine migrant juveniles), sometimes with rare and quick incursions in mesohaline waters (only 2 individuals). Other individuals (17%) showed consistently high Sr:Ca ratios (saltwater) through the otolith ratio from core to edge (Fig. 3 - Type 2) (marine resident juveniles). These two kinds of Sr:Ca profiles were only recorded in individuals catch in Tromomó.

The majority of the individuals caught at Guaraguacú showed consistently medium values of Sr:Ca ratios from the core to otolith edge (brackish water) with a few incursions in oligohaline (freshwater) water (Fig. 3 – Type 3) (brackish resident juveniles with occasional freshwater entries). Other (10%, i.e. 6 individuals) remained in mesohaline waters through their life-time (Fig. 3 - Type 4) (brackish resident juveniles). Other individuals (10%) (Fig. 3 - Type 5) recorded high Sr:Ca ratios in the otolith's core (marine water), after which they recorded medium and constant Sr:Ca ratios values throughout their remaining life history (brackish migrants juveniles), in some cases with a few incursions in oligohaline waters (Fig. 3 - type 6) (downstream migrants juveniles).

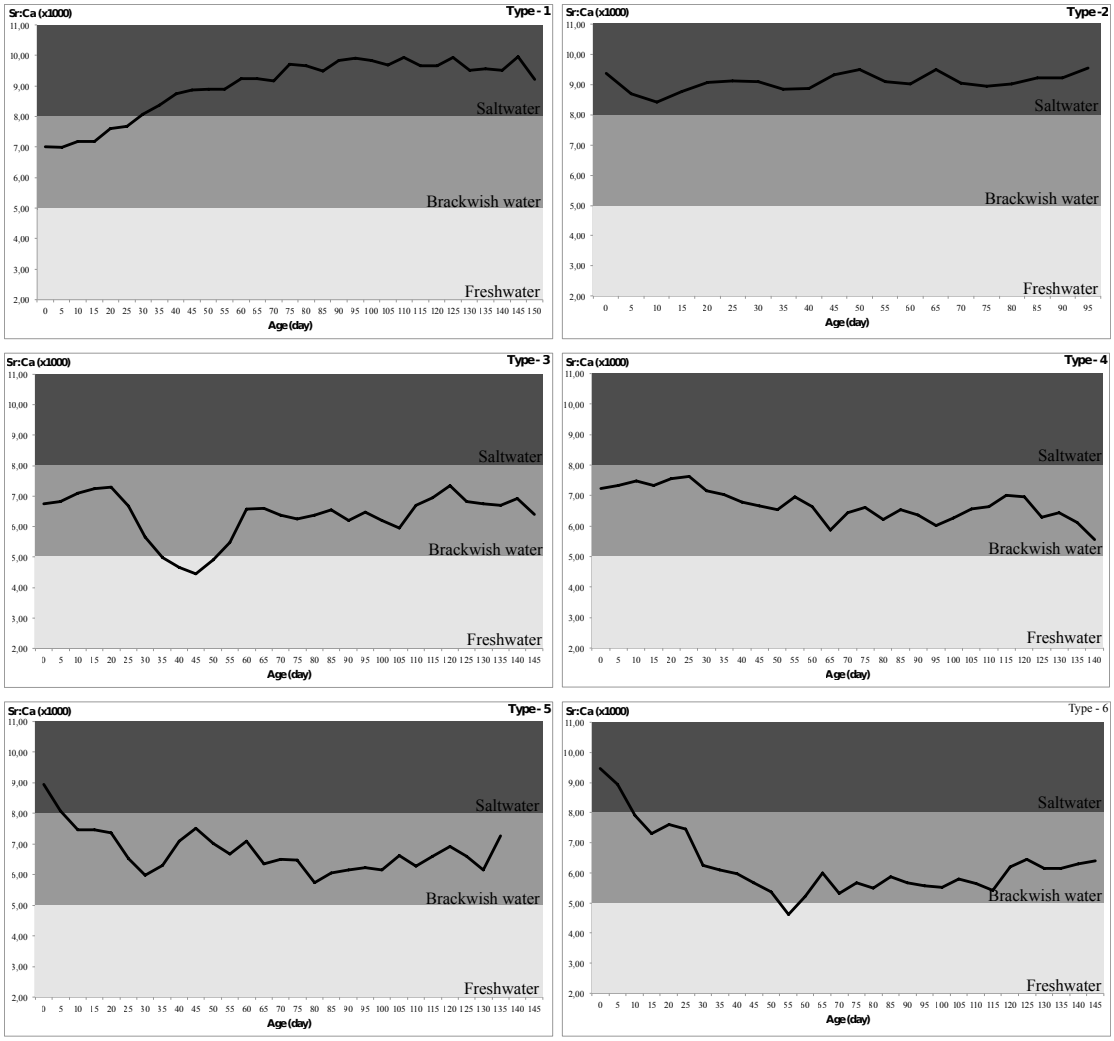

Fig. 3. Otolith transects types of residency patterns of *Centropomus parallelus* from the core to the edge. Tromomó, Types 1 and 2; Guaraguaçu, Types 3, 4, 5 and 6.

The primary increment width pattern through the otolith radius showed a similar general pattern for all individuals There was an abrupt increase of the primary increment widths from the larval hatching until 20 days of age, remaining relatively constant (~18 µm) until 60 days, after which the increment width start to decrease. Tromomó individuals showed however a slightly higher otolith growth rate from 60 days afterwards (Fig. 4).

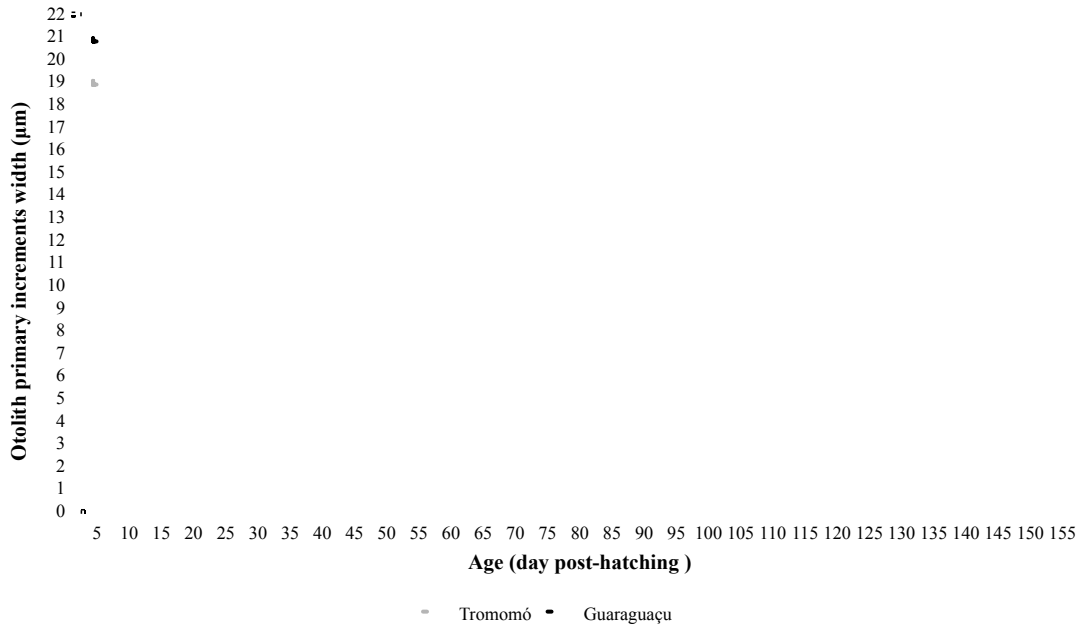

Fig. 4. Profile of otolith increment average widths for the individuals collected in Tromomó (gray line) and Guaraguaçu (black line).

DISCUSSION

To date studies about the habitat use of *C. parallelus* juveniles were only accomplished across species-specific catches in estuarine environments suggesting a meso-oligohaline habitat preference for the species (Aliaume *et al*., 1997; Itagaki ,2005; Chaves & Nogueira, 2013). The obtained Sr:Ca concentration ratios in juveniles of *C. parallelus* caught in PEC are within the range of values reported for other estuarine fish species (Chang *et al*., 2004; Diouf *et al*., 2006, Yang *et al*., 2011).

This study showed from the Sr:Ca ratios observed in the otoliths that juveniles of *C. parallelus* have a high environmental plasticity in terms of habitat salinity residence and movement. This behavior was expected based on the frequent record of *C. parallelus* individuals within the PEC in areas of different salinities (Felix *et al*., 2007; Contente *et al*., 2011; Vitule *et al*., 2013). Furthermore laboratory

experiments showed that grow and survival of individuals were not significantly affected by salinity shifts (Tsuzuki et al., 2007; Sterzelecki et al., 2013).

Back calculation estimates from daily increments recorded in the otoliths indicate that *C. parallelus* has a protracted spawning season from May to January, with a peak between October and January (spring/summer). Two spawning seasons have been already observed in the Cananéia (Itagaki, 2005) and Guaratuba Bays (Chaves & Nogueira, 2013) in spring and autumn, and late summer and early autumn, respectively. It seems that even at short distances (about 100 km), i.e. between nearby estuaries, the *C. parallelus* temporal reproductive period could slightly differ. This reproductive plasticity behavior within the species could be related with the spatial environmental conditions, such as tidal cycles, rain regimes and drainage areas (Gilmore et al., 1983; Tucker & Campbell, 1988; Tilmant et al., 1989). This could favor the larval dispersion of eggs, larvae and early juveniles for the nearby nurseries areas (Itagaki, 2005), allowing low levels of competition, a reduction of the risk of predation and good food availability.

The Sr:Ca ratios in the otolith's cores of *C. parallelus* which represent the natal origin of the fish, suggest that the spawning occurs preferentially in a mesohaline environment, although spawning in saltwater was also observed. Due to the wide area of the PEC with the existence of several mesohaline environments inside (Noernberg et al., 2006), is difficult to point precise–spawning grounds. However, some studies indicate that spawn occurs near the mouth of the rivers, probably within estuarine systems (Seaman & Collins, 1983; Della-Patrona, 1984; Itagaki, 2005). The spatial proximity between the spawning and the nurseries areas in *C. parallelus* could represent a species advantage by decreasing the larval

dispersion time and the settlement period which as result reduce the predation risk (Itagaki, 2005).

As an important fish species for aquaculture purposes (Corrêa & Cerqueira, 2009) several experiments showed that *C. parallelus* juveniles can grow and survive in salinities ranging from 0 to 35 psu (Tsuzuki et al., 2007; Sterzelecki et al., 2013). Although a higher food uptake was been observed at low salinities (Rocha et al. 2005), a successful larval hatching rate and fish development was recorded preferentially at 30 to 35 psu (Araujo & Cerqueira, 2005). The somatic growth rate inferred from the observed daily otolith increment width profiles suggest a high fish grow rate until the 20 days of age (first phase), followed by a constant growth rate until the 60 days (second phase), and thereafter a decreasing growth rate until the moment of fish capture (third phase). According with the current knowledge of the early life history of *C. parallelus* (Itagaki, 2005), it could be assumed that the first, second and third stages are related with the larval development (including the larval hatching and the first exogenous feeding), metamorphosis and settlement, and the beginning of the juvenile stage. Furthermore it is well known that the formation and deposition rate of the daily increments, besides being strongly influenced by ontogenetic events, is also close related to several abiotic factors (Campana & Neilson, 1985). The fact that the Guaraguaçu and Tromomó individuals recorded a higher growth rate in the second and third stages, respectively, is probably related with the salinity of the collecting areas. Although salinity does not appear to affect growth and survival of *C. parallelus* (Tsuzuki et al., 2007), a better food uptake (important after the absorption on the yolk sac) and fish development (onset of the juvenile stage) occur preferentially at low and high salinities, respectively (Araujo &

Cerqueira, 2005; Rocha et al., 2005).

It is accepted that early juveniles of the Centropomidae family present some kind of site fidelity after the post-larval settlement, although they can perform short migrations (Itagaki, 2005; Barbour & Adams, 2012). But how to explain why the individuals of Guaraguaçu presented more Sr:Ca ratios profiles than the Tromomó individuals (4 vs 2). This is probably associated to different morphological conditions of the collection sites. It is well known that the variation of the salinity in the lower estuary (Guaraguaçu) is higher due to the rain and tidal regimes exposure (Contente et al., 2011). By contrary Tromomó is located in the mouth of the Serra Negra river, in the border of the Benitido sub-estuary, where the salinity is more related with the tidal cycles, and less with the freshwater outflow (Noernberg, 2001). Tromomó could be considered a more stable and homogeneous water environment in terms of salinity. The salinity changes experienced by the individuals of type 1, from meso to polihyaline waters, from poli to mesohyaline waters in types 5 and 6, and from meso to oligohyaline waters in types 3 and 6, are coincidental with the age of the larval settlement (18 days according to Itagaki, 2005), and with the transition from the larval to the juvenile stage (40 to 56 days in the lab and wild environments, respectively, according to Alvarez-Lajonchère et al., 2002 and Itagaki, 2005). The hereby observed high plasticity of *C. parallelus* could allows higher survival rates since the swimming system of the larvae and post-larvae individuals is not fully developed and they are passively drift by the water currents during its early life history periods.

The data shows that *C. parallelus* could occupy diverse salinity habitats and migrate among marine, brackish and freshwater areas within the Paranaguá

Estuarine Complex showing a high environmental plasticity and adaptation. This new ecological information is essential for a rational fisheries management of the species.

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Conclusão geral

O conhecimento acerca da ecologia das espécies de peixes é fundamental na identificação das unidades populacionais ou estoques, no estabelecimento de rotas migratórias e no estudo da conectividade entre os ambientes, sendo estas informações, fundamentais para o manejo e conservação integrado e racional das espécies.

A comunidade de peixes de costão rochoso das ilhas costeiras do litoral do Paraná e adjacências são dominadas por poucas espécies, taxônomicamente similares, com distribuição geográfica ampla, predominada por espécies com hábitos tróficos generalistas, e diferindo em relação a abundância e biomassa. Os dados apresentados sugerem que a Ilha de Itacolomis, por apresentar maior riqueza, abundância e biomassa, é uma forte candidata a compor uma unidade de conservação.

A assinatura química dos otólitos inteiros de *Stegastes. fuscus*, representando toda a história de vida, mostrou que a população está dividida em 3 grupos na área estudada, baseado na distância / semelhança entre os estuários, mostrando que existe uma distinção em pequena escala nas relações elementares e isotópicas. Os resultados obtidos podem ser úteis para os futuros estudos de conectividade utilizando a assinatura química do núcleo e da borda do otólito (assinaturas natais e de captura, respectivamente) para avaliar a contribuição dos juvenis oriundos de cada ilha para a o recrutamento da população adulta na região costeira.

A Relação Sr:Ca nos otólitos dos juvenis de *Centropomus parallelus*, sugere que a desova para esta espécie ocorre preferencialmente em um ambiente mesohalino, e migrando posteriormente os indivíduos para habitats com diferentes salinidades, transitando entre a água doce e marinha no Complexo Estuarino de Paranaguá, mostrando assim uma alta plasticidade ambiental. O aprofundamento deste estudo, com a inclusão de indivíduos adultos e um maior número de pontos amostrais com diferentes salinidades, poderá determinar o padrão migratório e o uso do CEP pela espécie, auxiliando no manejo.

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